TRANSACTIONS OF

THE ROYAL SOCIETY OF CANADA

SECTION IV
GEOLOGICAL SCIENCES
INCLUDING MINERALOGY

THIRD SERIES—VOLUME LII—SECTION IV
JUNE, 1958

OTTAWA
THE ROYAL SOCIETY OF CANADA
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SECTION FOUR

PRESIDENTIAL ADDRESS

Co-ordination of Geological Surveys in Canada

H. C. RICKABY, F.R.S.C.

THIS paper is somewhat different from those usually presented before Section IV of the Royal Society of Canada. It deals largely with administrative matters in the field of geology as opposed to research in geology both as a pure science and as an application to the development of our natural resources. The relationship between the Geological Survey of Canada and the geological branches of the provinces has always been, in general, a satisfactory one although, as far as I know, there has never been any clear understanding as to the fields in which they are to operate. It would be difficult, perhaps impossible, to set up any definite regulations in this respect in a country such as Canada which has such vast resources in minerals varying greatly across the Dominion and from province to province. From time to time, however, differences—fortunately mostly of a minor nature—have arisen between officials directing the federal Survey and those of the provinces covering the fields in which they wish to carry on geological work. In Ontario the usual procedure is that, some time prior to the field season, the Head of the Provincial Geological Branch consults with the Director of the federal Survey on the areas to be covered and the nature of the work to be done. I am led to believe that somewhat similar arrangement is made in each of the other provinces. It is suggested, however, that some study might be made of the most effective utilization of both organizations, bearing in mind their respective facilities and obligations.

The purpose of geological work in Canada apart from advancing our knowledge of the science of geology is to learn as much as possible of the geology of the country as quickly as possible. Some of you may recall a paper entitled "The Exploitation and Conservation of Mineral Resources in a Balanced Development of Canada" by Dr. J. J. O'Neill read before this Section in 1940. In this very important paper the author in referring to the mining industry said, "If mining must be used as a lever to open up new country and to maintain its population and services until permanent industries are established, it will be fatal if we neglect to secure all possible geological information as to its potentialities in every part of the country." Later on with reference to what the provinces should do, he stated, "It is the duty of the provinces to do everything in their power to make the resources available and exploitable in an orderly manner, but geology knows

no political boundaries and is a national concern." I think that we are all in agreement with the above two statements.

I am advised by Dr. J. M. Harrison, Director of the Survey, that as of February 20, 1958, the staff of the Geological Survey of Canada comprised 127 members with degrees in geological or closely related sciences. Of this professional staff, 105 were engaged in field studies, mostly on regular mapping. This number sounds impressive and yet when viewed in the light of the amount of field work still to be done it seems regrettably small. In this connection it might be pointed out that one large oil company and one base metal company operating in Canada employ respectively eighty and seventy-five geologists or geophysicists full time. The Geological Survey of Canada endeavours to spread its operations more or less uniformly over all of Canada, but since it is the only government agency for geological work in the Yukon and the Northwest Territories, it is obliged at the present time, and presumably for some time in the future, to spend much of its effort on field work there. Moreover, in the case of at least two of the provinces, British Columbia and Newfoundland, it has special obligations under the terms of the entry of these provinces into Confederation. Finally, the administration, and presumably the geology, of the Indian lands and the national parks is under its direction.

In the *Report* of the Royal Commission on Canada's Economic Prospects published in December, 1956, there is a strong recommendation for further expansion of the Geological Survey to enable it to step up the rate of mapping and surveying of Canada. In the chapter on mining and mineral processing the Commission reports: "Less than one third of Canada has been mapped and an even smaller portion surveyed on a scale adequate for mineral exploitation. If a geological map of the country is to be completed within reasonable time, and if the expansion of the mining industry is to be facilitated, the excellent work of the Geological Survey should be speeded up through an expanded program limited only by the number of suitably qualified people available." It is important to remember, moreover, that the preliminary geological survey of most areas only indicates certain targets where much more detailed surveys will eventually be necessary. Consequently, even though we may look forward to the day when a geological map of the whole of Canada may be completed, our provincial geological branches and the Geological Survey will nevertheless continue to function.

All the provinces of Canada, with the exception of Prince Edward Island, have, at some period following their entrance into Confederation, set up geological branches either directly under the department which deals with mineral resources or under a provincial research council, as in Alberta. The number of technical personnel in geology and the related sciences in each province naturally varies more or less in proportion to the extent of its mineral resources. There is, however, no question of the necessity of there being provincial departments to carry on detailed geological work since the ownership of minerals is in the Crown in the right of the provinces. If

the mining lands in the provinces are to be efficiently administered there must obviously be first-hand information on their detailed geology. The much greater size of the staff of the Geological Survey of Canada naturally permits more specialization in certain aspects of geological work. In Ontario, since the organization of a geological branch in 1902, certain fields have been largely allocated to the federal Survey. For example, most of the work on the sedimentary rocks from the Cambrian upwards (the so-called soft-rock geology) has been done by the Survey. The provincial branch has concentrated its work on the Precambrian rocks which are more important from the standpoint of precious and base metals and iron ore. Ontario was, of course, one of the provinces that received much attention from the Geological Survey from the time of the formation of the Survey in 1842 and has continued to receive its share since the formation of its own geological branch. I imagine that the other provinces have been similarly treated.

A statement of the aims and policy of both federal and provincial surveys would serve to clarify their respective fields of responsibility. The guiding policy on geological surveys made by the Ontario Department of Mines was outlined by the late T. W. Gibson in his book entitled *The Mining Laws of Ontario and the Department of Mines* published in 1933. Under the heading, "Purpose of Geological Investigations," he states,

> Keeping in view the object for which the Department of Mines exists, as stated in the original Act, namely, to aid in promoting the mining interests of the province, its policy from the beginning has been to make its geological work as practical as possible. While by no means neglecting the scientific and technical aspects of its investigations commercial rather than academic considerations are regarded as of prime importance. It is not suggested that purely scientific studies are not important, and as a matter of fact, experience has provided cases of strictly geological studies, without economic ends in view, that have proved of much value as a guide to the location of mineral deposits. But the charter of the Department of Mines as contained in the Act of 1891 requires its efforts to be aimed at promoting the interests of the province and this is the object it has ever had in view.

If this approximates the policy of the other provincial geological surveys it would, theoretically, leave the field of broad fundamental geological studies, both field and laboratory, largely in the hands of the federal Survey. Adequate funds for fundamental research in all branches of geology and geophysics should thus be made available to the Survey for this purpose. However, because there is really no sharp dividing line between the scientific and the practical it would be unwise to lay down specific regulations. Nevertheless, an understanding will always be necessary between the different governmental surveys.

The relationship between the United States Geological Survey and the state surveys is apparently somewhat similar. The functional relationships have never been "spelled out" but have been worked out through liaison between officials of the federal Survey and the state geologists, apparently with reasonably satisfactory results. The situation has been set out in part

in a memorandum dated September 27, 1954, from W. H. Bradley, Chief Geologist of the United States Geological Survey, addressed to all the supervisors. Dealing with the main functions of the federal and state surveys he states: "The fundamental job of the Survey is to do those things that are in the national interest that cannot or will not be done by others, or cannot be done effectively by others." Further on he says: "The state geological surveys, on the other hand, are primarily interested in problems within their own states, and if properly financed and staffed, can do those things eminently well."

That conflicts have arisen at times is also indicated in the memorandum where he states: "The national and state requirements for effective geologic work are so huge that if we talk with one another, none of us need step on anyone's toes." Finally, and I think this is very important, he adds: "Moreover, I believe it is clearly to the advantage of both the Survey and the State surveys to strengthen each others' hands when the opportunity presents itself."

Today there is another group that is making enormous contributions to our knowledge of the geology of Canada, namely, the private companies. In some parts of Canada the exploratory and operating companies are, collectively, accumulating more geological information than the government geological surveys. Much of this information is naturally not available to the public, but in any scheme of national planning for co-ordinated geological studies the place and contribution of the private companies should be taken into consideration.

In conclusion, it stands to reason that the present arrangement even if undisturbed will continue to show progress. Nevertheless, in this age of planned economy, it would seem logical to expect that some definite understanding as to the fields of the federal Survey and those of the provinces would assist in a more rapid attainment of our objective. This objective is a reasonably accurate knowledge of the geology of all parts of Canada. Naturally, if a study were to be made, any regulations or rules set up as the result of it would be subject to modifications to meet the wishes or requirements, either political or otherwise, of each of the parties concerned. The next problem that arises is how such a study is to be carried out. There must, of course, be a request from some association to the governments concerned for such action to be taken. In this respect I would refer again to Dr. O'Neill's paper on the broader programme of the exploitation of our mineral resources. The last paragraph in that paper runs as follows: "The government should be requested to set up, without undue delay, a competent organization for national planning for a balanced development of the country. Such a request should come from a body of men qualified to weigh all factors of the situation and to give a dispassionate judgment without any suspicion of self-interest or prejudice. I could think of nobody more competent to take such action than the members of the Royal Society of Canada." May I add that, in view of the somewhat narrower objective behind this paper, the request should be at least initiated by Section IV of the Royal Society of Canada.

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SECTION FOUR

Structural Features of the Northern Part of the Labrador Trough

R. BÉLAND and P. E. AUGER, F.R.S.C.

ABSTRACT

Most of the Labrador Trough is pictured as an asymmetrical geosyncline which began as a half graben. But the Payne Bay–Roberts Lake segment is a semi-isolated basin along the rim of which the same sedimentary formations outcrop continuously.

The structural lineaments in the basin have the same attitudes as in the main part of the Trough at Leaf Bay. Along the east side dips are steep, with overturning, and contacts are sheared. Along the west side the rocks are less deformed, and the folding has been influenced as much by the shape of the Archaean floor as by tectonic shoving from the Northeast.

At Ford Lake, the thicker parts of the iron-formation lie in embayments and show evidence of lagoonal deposition.

Dual Asymmetry of the Labrador Trough

The Labrador Trough is 600 miles long and fifty miles wide, and is thus the largest of the depositional basins that here and there interrupt the continuity of the Archaean rocks in the Quebec Precambrian. Tectonically, the Labrador Trough is pictured (1;2;3;4) as a half graben, the east side of which subsided deeper and faster than the west side, which behaved like a semi-stable shelf. To the east of the subsiding furrow rose a geanticlinal welt that supplied volcanic rocks and greywacke suites of sediments to the east side of the Trough, while the western side was receiving paralic sediments from a mature continental surface.

Orthoquartzite, "iron-formation," some euxinic black shales, and thick calcareous formations occur in the western part, whereas eugeosynclinal rock assemblages, lavas, and gabbroic intrusives fill the central and eastern parts of the Trough. Basic and ultrabasic plutons and, in at least the southern part, porphyritic granites with corteges of satellitic porphyries, are practically limited to the eastern margin of the Trough.

Grades of metamorphism increase markedly across the Trough from its western margin eastward. The western paralic rocks show no, or only incipient, metamorphism. In mid-Trough, the lavas generally belong to the greenstone facies. Near the eastern margin, the pelitic rocks reach the staurolite-cyanite isograd.

On this lithological asymmetry is superimposed a structural asymmetry which manifests itself in four ways: (*a*) The western paralic rocks, though intricately wrinkled locally, are generally less deformed than the rocks of

other parts of the Trough and, as a rule, dip uniformly at 20° to 30° east or northeast. (*b*) In the central and eastern parts of the Trough, the folding is generally asymmetrical: the west limbs of major anticlines are very steep or overturned. (*c*) Reverse and thrust faults dip northeasterly and, in general, hanging walls have been shoved westward. (*d*) The western and eastern contacts between the Trough rocks and the Archaean gneisses differ markedly. The western contact is a textbook unconformity with basal conglomerates and grits, truncation of gneissic structures by the gently dipping bedded rocks, and so on. The eastern contact, however, presents one of the major geological problems of the Trough.

Obviously, these two asymmetries—the lithologic and the structural—are both, to some extent, manifestations of the same tectonic asymmetry. We prefer to think of them separately, however, because north of Payne Bay the structural asymmetry persists although the lithologic asymmetry is absent.

Structural Features of the Northern Part

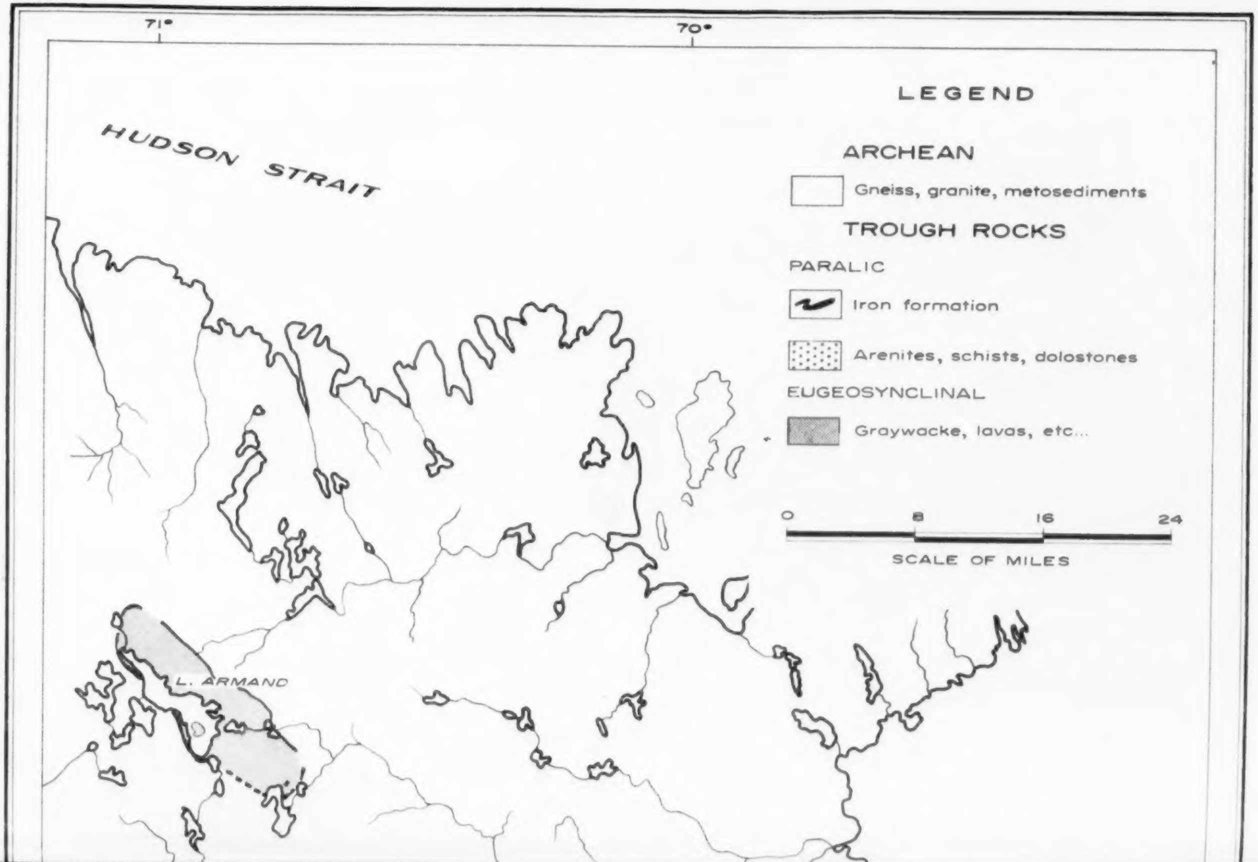
Area Investigated, and Sources of Information

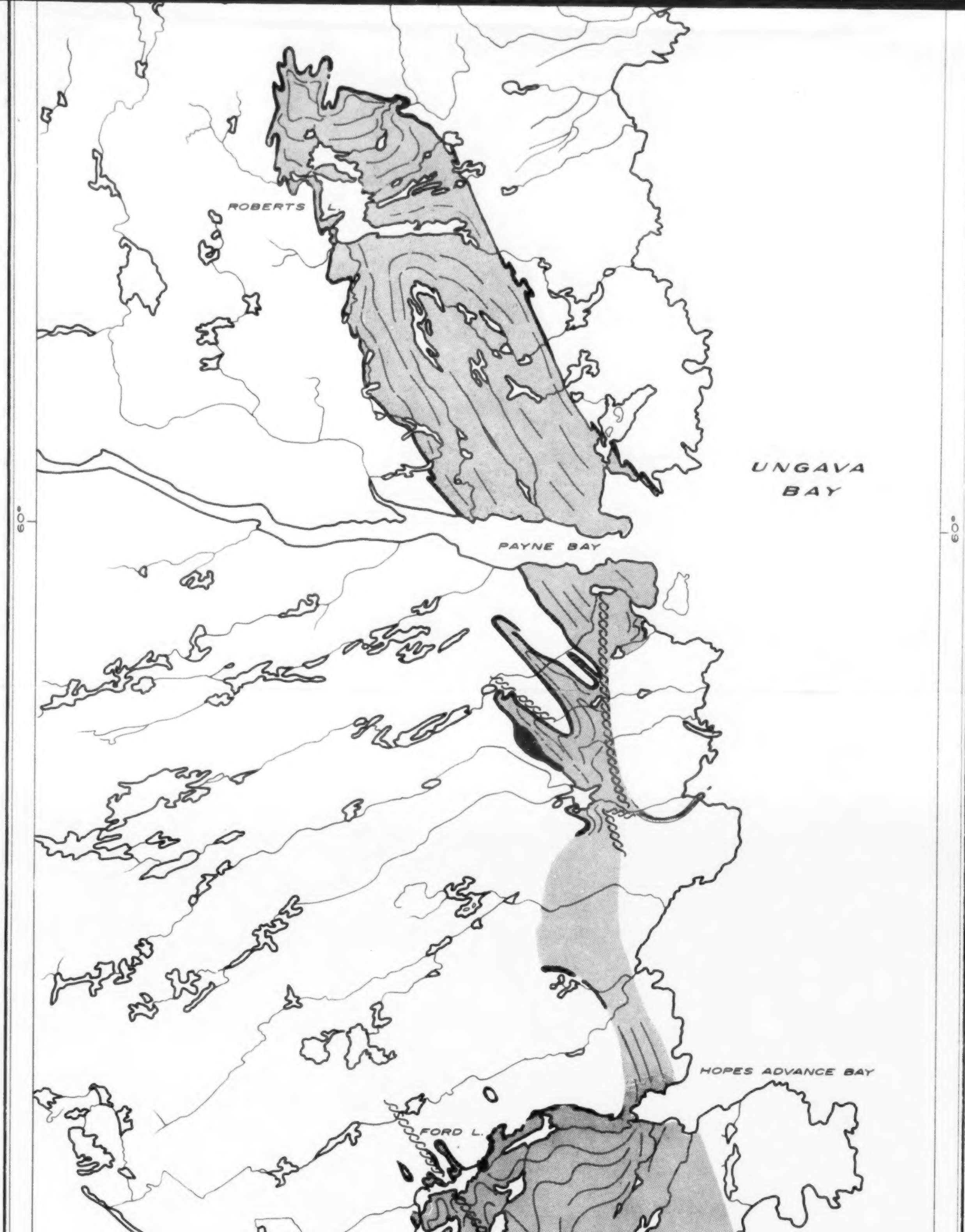
The northern Labrador Trough, as herein considered, extends from Lake Gerido to Roberts Lake and includes a small closed basin around Lake Armand. It is the area represented in Figure 1. From 1951 to 1957 we have seen, mapped or diamond drilled most of the areas under discussion. Most of the information in the area south of Leaf Bay comes from detailed work done by the authors along the western margin of the Trough. This was supplemented by numerous visits of the senior author to the central and eastern parts of the Trough and by the valuable reports and maps of Bergeron (5;7;9;13), Sauvé (6;10;11;14), Bérard (12;15), and Gélinas (16;17) of the Department of Mines, Quebec. The Lake Armand region is not well known. The results of preliminary explorations were made available through the courtesy of Quebec Explorers Limited. In the area immediately south of Payne Bay, the work of Bergeron (1956) has supplemented our own observations. The writers are indebted to the mining companies working in the area, especially to International Iron Ores, Atlantic Iron Ores, Oceanic Iron Ore, and Consolidated Fenimore for their helpful cooperation and for permitting access to most of the geological data available.

Sinks and Saddles

The general outcrop of the northern Trough, with its constrictions and widenings, indicates a succession of sinks and saddles. The most obvious sinks are the Lake Armand and the Roberts Lake basins, which are separated from each other by a saddle of Archaean rocks. The constriction of the Trough north of Hopes Advance Bay corresponds to another important saddle.

On a smaller scale, the Roberts Lake basin is divided into two unequal sinks by a gentle anticlinal flexure which crosses the northwest–southeast


71°
70°
HUDSON STRAIT
LEGEND
ARCHEAN
Gneiss, granite, metosediments
TROUGH ROCKS
PARALIC
Iron formation
Arenites, schists, dolostones
EUGEOSYNCLINAL
Graywacke, lavas, etc...
0
8
16
24
SCALE OF MILES
L. ARMAND



ROBERTS L.
UNGAVA
BAY
60°
60°
PAYNE BAY
HOPES ADVANCE BAY
FORD L.

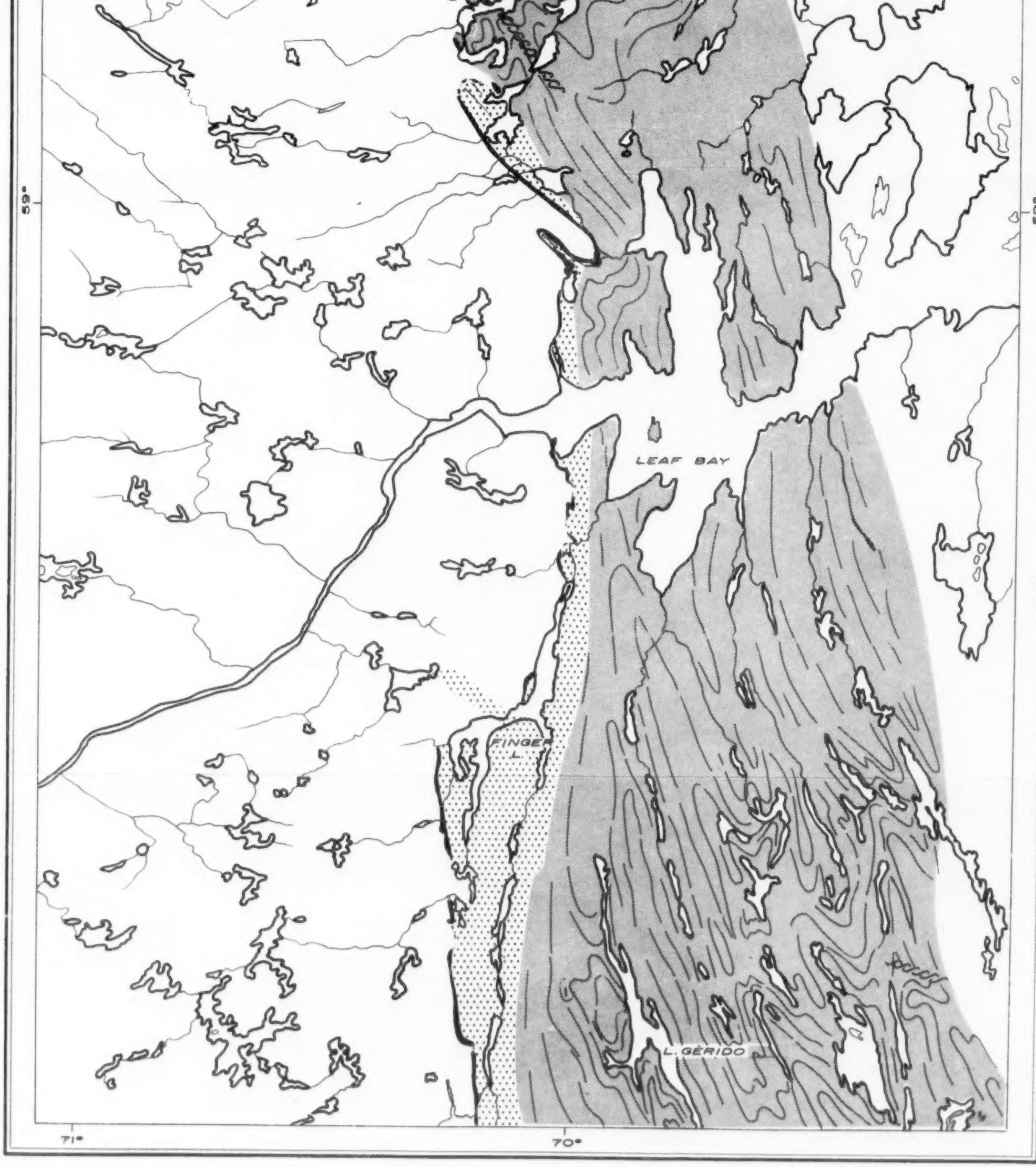


FIGURE 1.—North end of the Labrador Trough; Ungava, province of Quebec.

structural trend near the north end of Roberts Lake. Between Payne Bay and Ford Lake, some of the narrow embayments of iron-formation within the Archaean gneisses constitute semi-closed basins, which, like the Morgan Lake basin and similar ones at Ford Lake, have been studied in much detail as possible sources of iron ore.

Lithological Symmetry

The Roberts Lake basin has a simple synclinal structure in which the rock types outcrop on both limbs. The same beds of iron-formation have been traced continuously from Payne Bay along the eastern rim of the basin, around Roberts Lake, and back to Payne Bay along the western rim of the basin. The quartzites and pelitic rocks that are intercalated between the iron-formation and the Archaean gneisses are also continuous except for minor overlaps and onlaps, some of them caused by faulting. Everywhere around the basin these clastic rocks lie unconformably on high-rank gneisses, and there is no question that the foliated granitic gneisses, migmatites, agmatites, and other high-rank crystalline rocks are older than the Trough rocks. The central part of the basin is made up of mica schists, some garnetiferous, some calcareous, with thin lenticular sheets of serpentine ultrabasic rocks, and thin layers of greenstone-amphibolites which may represent either flows of lava or thin gabbroic sills.

South of Payne Bay, along the saddle which marks the south end of the Roberts Lake basin, the eastern band of iron-formation becomes narrow and disappears. This makes the tracing southward of the eastern boundary of the Trough extremely difficult because the sheared and granulated gneisses greatly resemble the metamorphosed rocks of the Trough.

Structural Asymmetry

Because of the exact repetition of sedimentary sequences, lying on identical Archaean floors on both sides of the northern Trough, it may be surmised that the conditions in which the sediments were produced, transported, and deposited were the same all around the northern Trough. The eastern border of the sedimentation trough must have been very similar in outline to the western border, with the same types and number of indentations and embayments. As shown in Figure 1 the outcrop of the eastern Trough rocks is straight but that of their western counterparts is very sinuous. This contrast is largely the result of deformation and shows that the structural asymmetry of the Labrador Trough persists up to its northern tip. The stresses induced by the great tectonic push from the northeast have been relieved through folding and flowage in the eastern part of the northern Trough, the western side being but slightly wrinkled. One thinks of surf breaking against a reef and producing only ripples in the lagoon behind. Thus the rectilinear outcrop of the eastern iron-formation, from Payne Bay to Roberts Lake, is that of steeply to vertically dipping beds, thickened in places by isoclinal folds in which overturning is frequent. Large scale maps

would show sharp bends and wiggles in the outcrop: these correspond to overturned, nearly recumbent folds. One such fold, just north of Payne Bay, is so spectacular that the hill in which it is exposed was called "Upside Down Mountain" by the prospectors who first visited the area.

Along the western border of the northern Trough, particularly west and southwest of Roberts Lake, and between Ford Lake and Leaf Bay, sinuosities of the outcrop of iron-formations correspond largely to embayments along the ancient shorelines. The embayments have been somewhat squeezed during deformation, especially where their long axes lay parallel to the "b" direction of the folding. But such deformation is not great, and dips remain below 40°. One embayment that we have mapped north of Leaf Bay trends northwest-southeast and is practically undeformed. From Leaf Bay to the south end of Finger Lake, the iron-formation beds dip from 10° to 30° eastward.

Where the Trough becomes very narrow at or near the saddles described above, deformations tend to show the same intensity across the whole diminished width of the Trough. Thus the Morgan Lake basin, though geographically belonging to the west side of the Trough, has a very complex structure. Strata are repeated by tight folding and thrust-faulting. Similar cases of tight folding combined with overthrusting may be observed in iron-formation beds along the north shore of Ford Lake and eastward to Hopes Advance Bay. In this section, however, there is a remarkable progression from west to east in the intensity of deformation. The embayments near the west end of Ford Lake show an open symmetrical type of folding. But near Hopes Advance Bay, folds are overturned, and blocks of Archaean gneisses have been sheared off and thrusted over and into the iron-formation beds. A similar increase from west to east in the tightness and overturning of folds occurs at the northern tip of the Roberts Lake basin.

The formations which occupy the central portion of the northern Trough have not been studied in detail. They also appear more tightly folded, and faults are more numerous on the east than on the west.

The Eastern Boundary of the Trough South of Leaf Bay

The eastern boundary of the Labrador Trough south of Leaf Bay is difficult to locate because of the combined effect of intense deformation and the high grade of metamorphism which has resulted in the transformation of Trough rocks and basement rocks alike into strongly foliated gneisses. Some of our observations in the northern Trough may supply data toward the solution of this geological problem.

Metamorphism in the Northern Trough

We have succeeded in establishing the eastern limit of the Trough at Hopes Advance Bay and along the north shore of Leaf Bay by applying two criteria worked out at Ford Lake. As far south as the north end of Finger Lake, there is no discernible difference of metamorphism across the northern

Trough. All the rocks belong to the albite-amphibolite facies. The basal quartzites are glassy, and contain "sponge" garnets and sheaves of cummingtonite. All the pelitic rocks are biotite schists, some with garnets. The layers which compose the so-called metallic member of the iron-formation are either specularite-rich schists or magnetite-rich quartzites. The iron-rich silicates which occur in these beds are biotite, barkevikitic, and gruneritic amphiboles, with minor chloritoids. The carbonate member of the iron-formation, particularly in places of intense deformation, consists mainly of matted cummingtonite or tremolite, and quartz. Consequently, in places of severe deformation, the problem of distinguishing between mica schists belonging to the Trough and sheared Archaean gneisses which have become fissile and micaceous also exists along the west side of the Trough, particularly at Ford Lake, as well as along the east side of the Trough north of Payne Bay.

A first criterion is based on the position of pegmatites. The pegmatites are abundant in the Archaean gneisses, but none has ever been encountered in the iron-formation, every foot of which has been examined,[1] nor in the basal sedimentary rocks of the Trough. We therefore take as the unconformity at Ford Lake the plane or zone at which pegmatites disappear. By applying the same criterion at Hopes Advance Bay where iron-formations do not exist, it is possible to locate the eastern boundary of the Trough.

A second criterion for locating the same boundary is provided by the observation that the schistose Archaean rocks are more sericitic and feldspathic than the Trough rocks which are rather quartzose and biotitic.

Obviously, as the Trough becomes lithologically asymmetrical toward the south, both from the stratigraphic and metamorphic points of view, these criteria become less applicable.

Existence of an Older Series of Metasedimentary Rocks

In the course of detailed mapping along the margins of the northern Trough, we have been impressed by the abundance, among the Archaean gneisses, of shreds and bands of hornblende-biotite gneisses, amphibolites, and quartzites injected by granite and pegmatite. Northeast of Ford Lake in particular, where the Trough rocks strike generally east–west, the granitic gneisses contain swarms of fragments, from one to ten feet long, of hornblende-biotite gneisses and quartzose paragneisses. Although general oriented parallel to the foliation of the granitic gneiss (which is oblique to the trend of the Trough rocks) many of these fragments have their internal foliation askew with respect to that of the granitic gneiss. In short, these fragments have been engulfed into the granite.

The most spectacular occurrence of such semi-granitized pararocks is to be found north of Ford Lake. The relationships are shown in Figure 2. A folded, layered quartzite, which, if it occurred within fifty miles of Montreal,

[1]If we except veins of mobilized quartz containing occasional crystals of red feldspars. Such veins are unsheared, and differ markedly from the Archaean pegmatites.

would be called Grenville, abuts on gently dipping Trough rocks including mica schists, quartzite, and iron-formation beds. In parts of the northern Trough then, Proterozoic rocks lie unconformably on an older series of metasedimentary rocks, more or less granitized, which may be assigned to

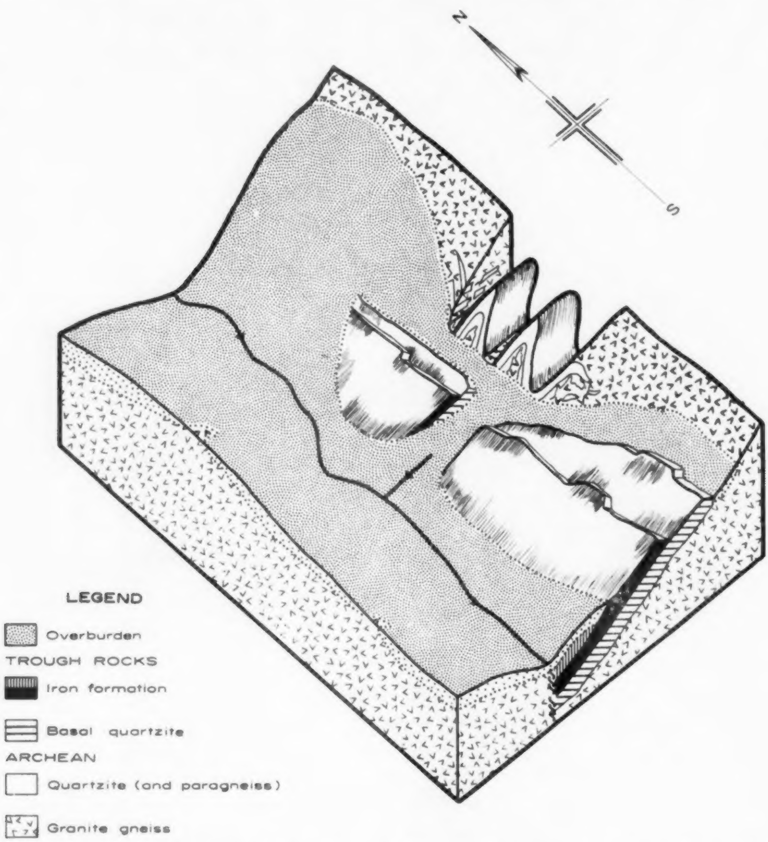


FIGURE 2.—Trough rocks (basal quartzite and iron-formation) truncating granite-injected quartzite and paragneiss north of Ford Lake.

the Archaean. In the example cited, the relationship is clear. It is conceivable, however, that where such Archaean paragneisses have the same trend as the Proterozoic rocks and where, moreover, the latter belong to a metamorphic facies close to that of the paragneisses, it may be impossible to define the limit of the Trough. This may be the case in the areas mapped and described by Sauvé (6;10) and Fahrig (8) along the eastern boundary of

the Trough. Both report sillimanite-bearing gneisses, and diopside-tremolite crystalline limestones, injected by granite. On the basis of such observations and by incorporating these high-rank crystalline rocks within the stratigraphy of the Labrador Trough, Fahrig (8) not only cannot find any unconformity between the Trough rocks and the granitic gneisses, but is forced to consider the latter as younger than the Trough rocks. We think that he may have looked for the unconformity at the wrong stratigraphic level.

Lagoonal Basins in the Old Archaean Floor

Several illuminating articles (18;19;20;21 *et al.*) have appeared within the last few years on the physical-chemistry of the deposition of iron-formations. All these papers point out that the optimum conditions of redox potential and pH should be met in lagoonal basins. From the geometric point of view, this means that embayments within the old Archaean floor of the northern Trough should contain the thicker and richer accumulations of ferruginous sediments. Conversely, iron-formation beds should thin out and be poorer in iron at the front of "landheads" along the ancient coastline.

Along the eastern margin of the Roberts Lake and the Morgan Lake basins the "shoreline" has been straightened by intense deformation. Dips are steep, beds are overturned, folding is of the close, almost isoclinal type, and any thickening of the iron-formation is probably a result of flowage rather than original accumulation.

Along the western side of the northern Trough, however, the thicker portions, or "blocks" as they are designated by mining people, of iron-formation correspond to embayments within the Archaean floor. In most places a great part of the thickening can be accounted for by local folding or thrust-faulting. We have found one locality, however, where the beds have uniform, relatively gentle dips, and where the effect of local deformation on the thickness of beds may be neglected. This block of iron-formation is situated about half way between Ford Lake and Hopes Advance Bay and is illustrated in Figures 3 and 4. The block has been accurately surveyed and diamond drilled so that the drawings represent true thicknesses and widths of exposure.

The greatest thickness of iron-formation is found in the deepest part of the embayment (section *A-A'*, Figure 3). Along the front of the landhead at the west end of the block (section *B-B'*, Figure 3) not only are the beds thinner but also the lowermost beds of clastic rocks are missing through lack of deposition.

Assays of the iron content and examination of the mineral compositions also show that the thinner iron-formation beds along section *B-B'* (Figure 4) are lower in iron content than the thicker section *A-A'* (Figure 4).

We think that detailed mapping and drilling would reveal more of these structures; in some cases the existence of bars closing the lagoons is suggested by small exposures of gneisses and by flexures in the overlying schists.

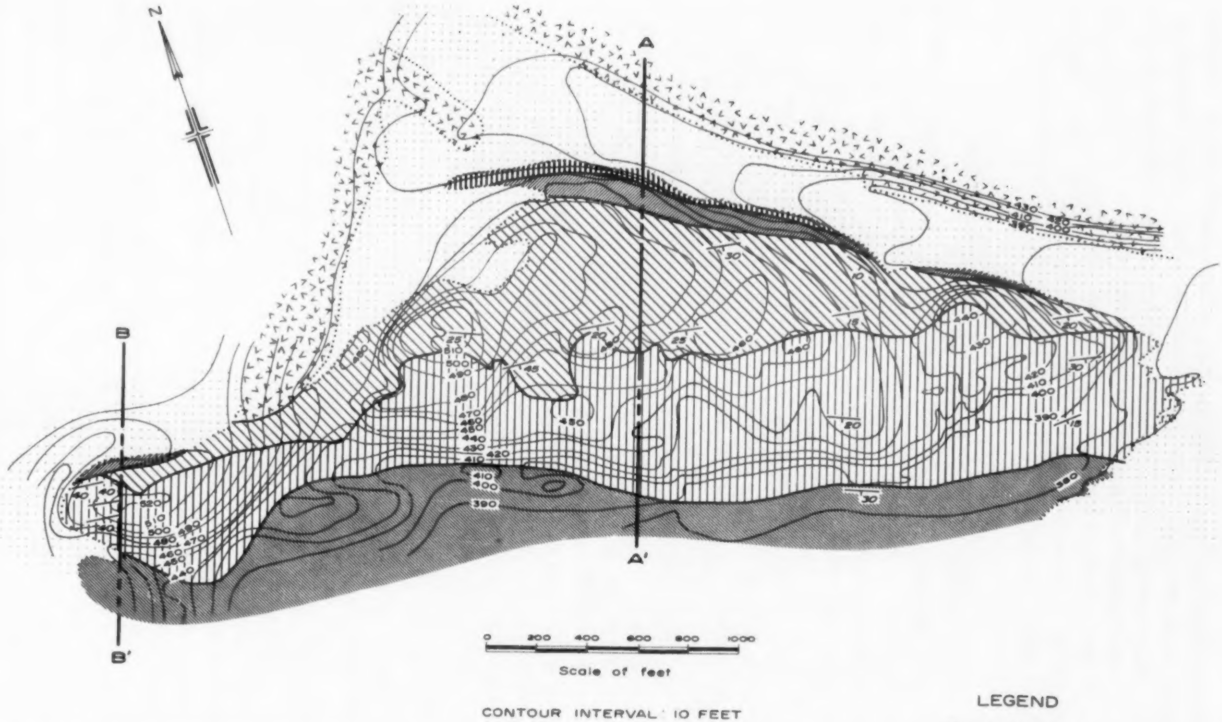


FIGURE 3.—Local thickening of relatively undeformed iron-formation in an embayment of the Archaean floor, northeast of Ford Lake.

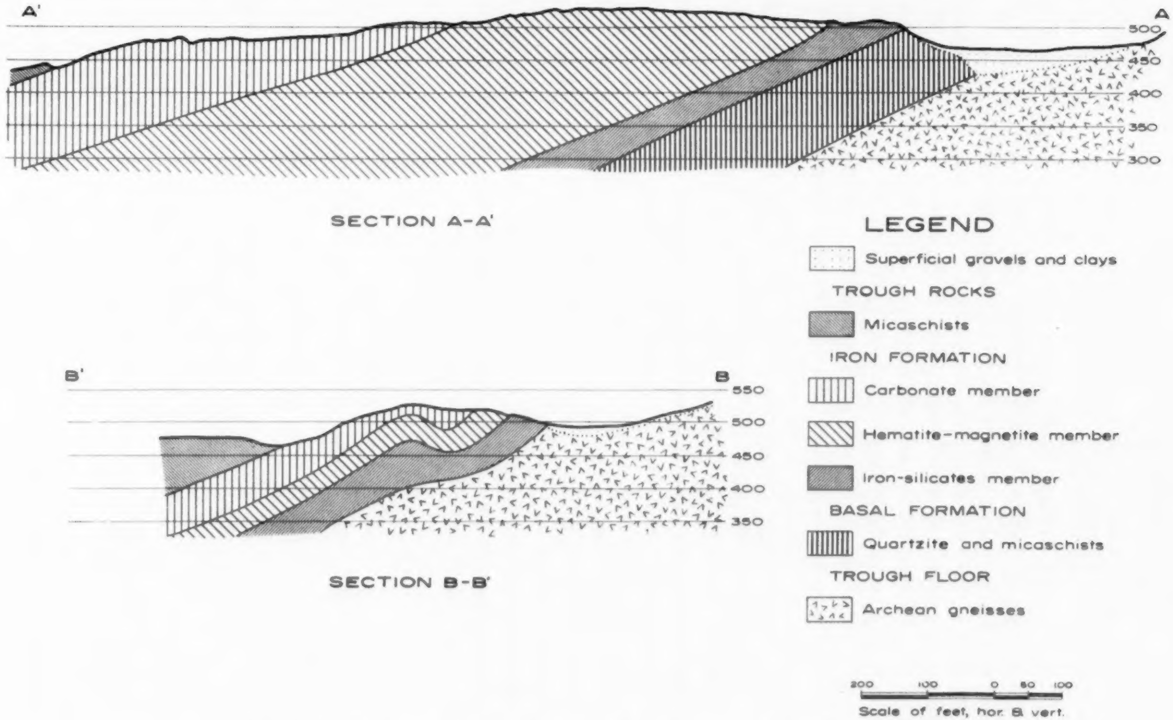


FIGURE 4.—Cross-sections through block of iron-formation shown in Figure 3.

Summary and Conclusion

The observations made by the writers and the conclusions arrived at in the present paper may be summarized as follows:

1. The Labrador Trough, uniform and continuous for some 600 miles, is terminated in the north by a series of saddles and sinks exposed for almost 100 miles and the northernmost sink is in fact an isolated basin.

2. Folds have the same northwest–southeast trend, the same asymmetrical pattern all along the Labrador Trough, right to its northern tip. In the main body of the Trough, the structural asymmetry corresponds to a lithologic gradation from unmetamorphosed paralic sediments on the west side to thoroughly recrystallized eugeosynclinal rocks on the east side. Lithologically, the northern Trough is a symmetrical basin: the same types of rock outcrop on both sides, and all belong to the same metamorphic facies.

3. One of the major problems of the Labrador Trough is the locating of its eastern boundary. Because of the lithological symmetry, the eastern boundary of the northern Trough is easily located.

Evidence has been presented of partly granitized, highly metamorphosed metasediments older than the Proterozoic Trough rocks. We submit that some of the other high-rank para-rocks recognized along the eastern boundary of the Labrador Trough may not be coeval with the Proterozoic Trough rocks, and that the Trough boundary should be sought stratigraphically above them.

4. At Hopes Advance Bay, the structure, distribution, and composition of the iron-bearing sediments seem to confirm the known theories on the deposition of iron-formation in lagoonal basins.

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SECTION FOUR

Palaeomagnetism and Continental Drift

P. M. DU BOIS

Presented by S. C. ROBINSON, F.R.S.C.

ABSTRACT

Palaeomagnetic measurements from several different continents are discussed. If the earth's magnetic field, averaged over a long period of time, is assumed to be that of a central dipole oriented along the earth's axis of rotation, then comparisons between palaeomagnetic measurements from different continents indicate that large relative movements between the continents have taken place. The basic assumption about the axial and dipolar nature of the earth's average magnetic field is theoretically reasonable and is supported by the experimental results from the Tertiary.

IN recent years great progress has been made in the field of palaeomagnetism and many measurements in several different continents have been carried out. At first the main interest in such measurements centred on the problems of reversals of the earth's magnetic field. Most workers now believe that the earth's magnetic field has in the past changed its polarity repeatedly although it is recognized that some ferromagnetic minerals have the property of reversing their magnetization spontaneously as the result of change in temperature or of the passage of time. However, such minerals are thought to be relatively rare, and most reversely magnetized rocks probably owe their polarity to a reversed magnetic field at the time of their formation rather than to the presence of unusual self-reversing ferromagnetic minerals. Furthermore, Hospers' work in Iceland (7), Roche's in France (14), Campbell's and Runcorn's (1) in the northwestern United States, and Irving's (8) in Australia have shown that in recent Tertiary time the average direction of the fossilized magnetic field, without regard to the sign of the polarity, found in the rocks at a particular locality corresponds to the direction of field produced by a magnetic dipole located at the centre of the earth and oriented along its present axis of rotation. Such a result is quite consistent with theoretical considerations which show that the Coriolis force, which is connected with the earth's rotation, must play a dominant role in the motions of the earth's fluid core, where it is thought that the earth's magnetic field is generated by some form of dynamo action.

In all the following interpretations of the palaeomagnetic data, the basic assumption is that the earth's average magnetic field is equivalent to that of an axial dipole, and if this assumption can be shown to be untrue, the suggestions of this paper can be disregarded.

When the fossil magnetizations of pre-Tertiary rocks were measured, it was found that the magnetization no longer corresponded to that expected

of a centrally located dipole oriented along the earth's present axis of rotation. Figure 1 shows how the directions of magnetization of Pre-Cambrian Keweenawan sandstones differ markedly from the direction of the earth's field at present. If we accept the Tertiary palaeomagnetic results and assume that the earth's average magnetic field throughout geological time can be represented by a dipole oriented along the axis of rotation, then the pre-

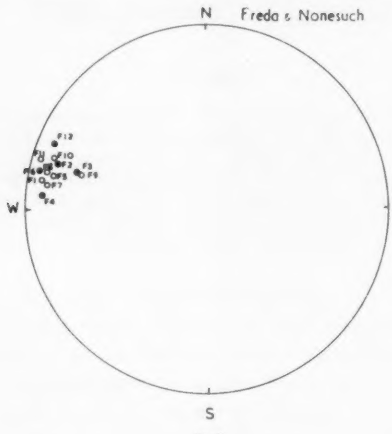

FIGURE 1.—Stereographic plot of the palaeomagnetic vectors of Keweenawan sandstones. (Full circles denote north poles on lower hemisphere, open circles denote north poles on upper hemisphere.)

Tertiary results must mean that the earth's axis of rotation has shifted relative to the land masses during geological history. At first it was thought that such a relative movement could be explained purely by a movement of the entire crust of the earth with respect to its axis of rotation, which, of course, must remain fixed in space, except for minor perturbations caused by other heavenly bodies. Both Munk (13) and Gold (5) studied the problems of such polar wandering theoretically and came to the conclusion that if one accepted as true certain reasonable assumptions about the properties of the earth's interior, one could show that polar wandering of the magnitude indicated by palaeomagnetism was indeed quite possible.

However, as results for single geological periods were accumulated from more than one continent, it became increasingly obvious that such a scheme of simple polar wandering could not explain all the experimental facts. Although results from a single continental mass gave consistent results (4), measurements from different continents were not compatible with one another, and it became necessary to reconsider the hypothesis of continental drift.

When pole positions are computed for the results of palaeomagnetic measurements from Europe and North America, it is found that the North American poles lie consistently to the west of the European ones (15;3). This discrepancy lies somewhere between 18° to 48° of longitude. The first question is, "Are there any systematic sources of error which could account for this discrepancy without invoking the need for relative movements between the two continents?" It is possible that the rocks from a particular period which have been measured and compared with one another on either side of the Atlantic are in fact not contemporaneous and that during the interval between their respective formations, rather rapid polar wandering displaced the position of the pole. This is a reasonable suggestion and criticism, especially as many of the palaeomagnetic measurements have been made on fine-grained red sandstones, which are often barren of diagnostic fossils and which are, therefore, not well dated. However, even if we admit that the relative dating of the formations sampled palaeomagnetically is not good, it seems improbable that the researchers in North America always managed to collect rocks which were formed when the polar wandering path had swung to the west while their colleagues in Europe always measured rocks which were laid down when the path had swung to the east. Furthermore, it is significant that, although the pole positions are displaced in longitude with respect to one another, their latitudes agree with one another fairly closely. This means that any polar wandering path invoked to explain these discrepancies would have to be along lines of latitude only.

Another explanation that could be called upon to explain the displacement of the poles is that, due to sedimentary and compaction processes, the inclination of the remanent magnetic vector measured in the rock is more nearly horizontal than the magnetic field at the time of formation. Workers who have measured the remanent magnetization of Pleistocene varved clays have long been aware that such is the case with this particular kind of sediment (11;6). Recently, experiments on artificially deposited varves (12) show that if the ambient magnetic field is neither horizontal nor vertical, the remanent magnetic vector will be shallower in dip. Such a flattening of the dips of the remanent magnetic vectors could produce some of the discrepancies between the European and North American results. However, it seems fairly certain now that many of the fine-grained red sandstones used in palaeomagnetic work have acquired their magnetization due to the precipitation of haematite after deposition, and it is unlikely that such a magnetization will be affected by sedimentary processes. Furthermore, since these same sandstones do not compact by much more than 2 per cent, compaction is not likely to affect the direction of magnetization. Also in many cases the remanent magnetic vector is nearly horizontal and is, in the light of the experiments on artificial varves, not likely to differ much from the vector of the ambient field at the time of formation. Finally, wherever measurements have been made on volcanics of the same age, no large dis-

crepancy between the two angles of inclination is found; and volcanic rocks are known to preserve the direction of the earth's magnetic field accurately.

Another process which might cause a systematic displacement of the pole positions is the acquisition by the rock samples of an isothermal remanent magnetization along the earth's present magnetic field. However, most of the palaeomagnetic results show little evidence of having been influenced by such an isothermal magnetization. If the magnetically hard and soft components were variable within a suite of rocks, one would expect the directions of magnetization in those rocks with the largest soft component to have

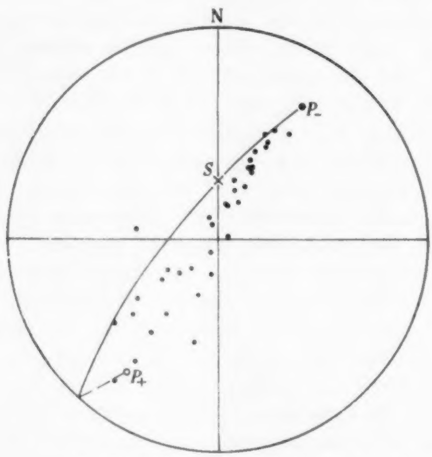

FIGURE 2.—Palaeomagnetic directions for Keuper marls showing "smearing" due to isothermal megnetization. S represents direction of the earth's field at present and P_- and P_+ are palaeomagnetic directions of stably magnetized rocks (after Creer).

moved farther along a great circle connecting the direction of the natural remanent magnetization and that of the earth's magnetic field than those with a smaller soft component. Such a distribution might be said to be "smeared" along the great circle, and an example of such "smearing" is shown in Figure 2. However, the great majority of the rocks have directions of magnetization which are tightly grouped and show no signs of such smearing. It is possible, of course, that if the ratio of original stable magnetization to acquired isothermal magnetization is constant for a suite of rocks, such rocks can acquire appreciable isothermal remanence without exhibiting smearing. Even if this rather improbable case were true and if the strata were flat-lying, then the isothermal remanence induced by the earth's present magnetic field would change only the latitude of the calculated pole position and not its longitude (15). On the other hand, if the strata have been folded so that the same rock formation can be found with different dips, the amount of isothermal remanence can be estimated and allowed for.

TABLE I

American Pole Positions			European Pole Positions			Pole Differences	
Formation	Lat.	Long.	Formation	Lat.	Long.	Lat.	Long.
Springdale	55°N	107°E	English Triassic	43°N	131°E		
Lavas from Holyoke, Mass.	54°N	90°E					
Conn. lavas and seds.	55°N	88°E					
Brunswickian	63°N	93°E					
Mean American Triassic	57°N	92°E	Mean European Triassic	43°N	131°E	14°N	39°W
Runcorn's Supai	26°N	121°E	Exeter traps	43°N	164°E		
Graham's Supai	43°N	113°E	Scottish lavas	36°N	175°E		
Doell's Supai	39°N	115°E	Scottish sediments	37°N	163°E		
Mean American Permian	36°N	119°E	Mean European Permian	39°N	167°E	3°S	48°W
Naco sandstone	41°N	120°E	English Carboniferous	48°N	138°E		
Mean American Carb.	41°N	120°E	Mean European Carb.	48°N	138°N	7°S	18°W
Freda and Nonesuch	9°N	169°E	Upper Torridonian	6°S	137°W		
Jacobsville	14°S	170°W					
Mean American very Late Pre-Cambrian	3°S	180°E	Mean European very Late Pre-Cambrian	6°S	137°W	3°N	43°W
Hakatai shale	31°N	150°W	Lower Torridonian	35°N	112°W		
Mean American late Pre-Cambrian	31°N	150°W	Mean European late Pre-Cambrian	35°N	112°W	4°S	38°W
			Mean differences between Poles			1°N ±6	37°W ±8

When one compares the pole positions for a single age as found in North America and Europe, one finds that the discrepancy between the pole positions is in longitude but not in latitude. Therefore, in these comparisons, isothermal remanence cannot account for the discrepancy. From Table I, in which the longitudes and latitudes of the various pole positions are listed, it can be seen that the differences in longitude range from 18° to 48°. These differences can be explained by assuming that North America has drifted westward from Europe some 18° to 48° in longitude since Triassic time. Such a westward drift can also be considered as a rotation of the North American continent about the present north geographic pole. This relative movement between Europe and North America is very similar in direction and magnitude to that originally proposed by Wegener (16) and other exponents of continental drift. Figures 3 and 4 show how the North American and European poles are brought together when one assumes that a drift of 40° of longitude has taken place.

Results from continents other than North America and Europe are too incomplete for detailed comparisons, but some are worth mentioning because they reinforce in a dramatic way the necessity for continental drift to explain the palaeomagnetic data. Clegg and his fellow workers (2) have made extensive measurements on the Indian Deccan Traps, which are either late Cretaceous or Eocene in age. The palaeomagnetic evidence from both Europe and North America is that at this time the geographic poles were not very far from their present positions. However, the Deccan results would indicate that one pole was in the Indian Ocean at 95°E and 28°S if we assume that India was at the end of the Cretaceous or at the beginning of

FIGURE 3.—Palaeomagnetic pole positions without continental drift. Triangles represent North American results and circles European results. The poles are numbered as follows: 1, late Precambrian; 2, very late Precambrian; 3, Carboniferous; 4, Permian; 5, Triassic.

the Eocene in the geographic position we now find it. On the other hand, if we assume that the geographic poles at the time were close to the present ones, then India must have been at a latitude south of the equator and must have drifted northwards some 54° of arc since Eocene times. It is worth noting that such a movement is of the same magnitude as that postulated between Europe and North America and that it agrees with Wegener and

FIGURE 4.—Palaeomagnetic pole positions assuming North America has drifted 40° of longitude westwards from Europe.

du Toit's classical hypothesis of drifting. A position 34° south of the equator would place India in pre-Tertiary times much closer to South Africa and Madagascar to which it has well-known faunal and floral affinities.

It is also worth noting that, if India was in its present position with respect to Europe during Permo-Carboniferous time, the position of the European Permian pole was such that India would have been in the tropical belt. However, the Talchir Series of the uppermost Carboniferous or lowest Permian contains evidence of extensive continental glaciation. Although orthodox geologists have attempted to show how such glaciation might have taken place because of the circulation of cold ocean currents from the Antarctic, it is very difficult, in the light of what we know about Pleistocene glaciation, to see how this mechanism could have worked. During Pleistocene times continental ice sheets formed almost exclusively at latitudes higher than 40°, but quite extensive mountain glaciation also took place at lower latitudes but at high altitudes. During Permo-Carboniferous times we have evidence that the climate in Europe and North America was very warm and tropical, and such a climate is quite consistent with the palaeomagnetic evidence from that part of the world. However, India, without continental drift, would also be in the tropics at that time, and if the world was suffi-

ciently refrigerated to cause glaciation in tropical India, there should also have been glaciation in Europe and North America, and there is no evidence that the glaciation in India could have been due to mountain glaciation.

In Australia the palaeomagnetic picture is rather similar to that of India. Recent palaeomagnetic measurements by Irving (8) on the Kuttung Permo-Carboniferous glacial varves show that they are magnetized in an almost vertical direction. These measurements are confirmed by Irving's work on volcanic lavas of the same age. These results, of course, indicate that during Permo-Carboniferous times Australia was situated close to a geographic pole,

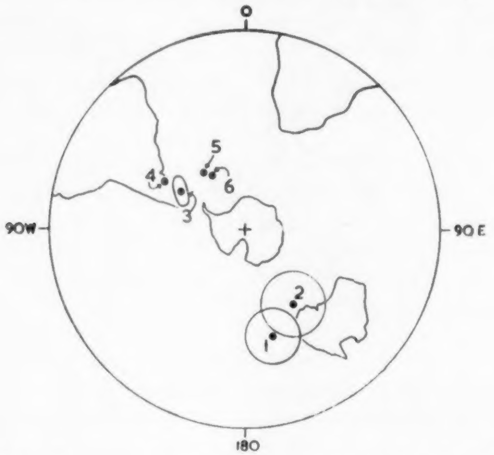

FIGURE 5.—Carboniferous pole positions. The poles are numbered as follows: 1 and 2, Kuttung varves and lavas of Australia; 3 and 4, Naco sandstones and Barnett shales of the United States; 5 and 6, Lower Carboniferous sediments and lavas of Britain (after Irving (8)).

and such a hypothesis is made more attractive by the presence in the Permo-Carboniferous stratigraphic column of deposits of extensive continental glaciation. As in the case of India, if Australia was in the same position with respect to Europe as it is today, the position of the Permian pole as computed from the European palaeomagnetic results was such that the Permian equator would pass very near to Australia. Thus, we can see that for this geological time the Australian palaeomagnetic and palaeoclimatological evidence, although it is quite consistent within itself, cannot be reconciled with the European results unless one assumes that Australia has moved almost 90° of arc with respect to Europe. This magnitude of movement is of the same order as that proposed by the proponents of continental drift. Irving and Green (9) have also measured rocks of early Tertiary age and have found that they too do not agree with the results from Europe. The palaeomagnetic results from India and Australia are shown in Figures 5 and 6.

In conclusion, it is fair to say that the palaeomagnetic evidence is now sufficiently extensive to justify a complete review by geologists and geophysicists of the objections raised to the original hypotheses of continental drift. It is striking how well palaeoclimatic and palaeomagnetic evidence agree. We know so little about the properties of the interior of the earth and how materials of the earth's mantle react to long-term stresses that it does not seem justifiable to eliminate continental drift on the basis of theoretical considerations. It is worth noting that a few years ago it was stated (10)

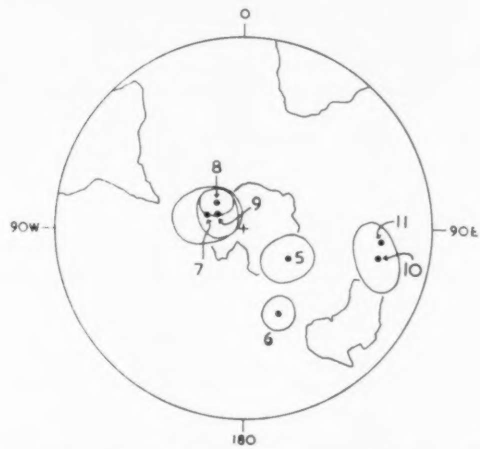

FIGURE 6.—Pole positions determined from Cretaceous and Lower Tertiary. Poles are numbered as follows: 5, Lower Tertiary lavas of Australia; 6, Tasmanian dolerite sills; 7, Oligocene of France; 8, Eocene basalts of Northern Ireland; 9, Dakota sandstones (Cretaceous) of the United States; 10 and 11, Deccan traps of India.

that Darwin had shown polar wandering could not occur, but Munk (13) has recently shown that not only were Darwin's calculations wrong but also that with certain properties for the earth's interior, polar wandering can take place. Hence, it does seem that we ought to review the objections to continental drift as objectively as possible, with more emphasis on the experimental facts and less on the theoretical arguments, especially on those arguments which are connected with our particular pet theories about mountain building and the origin of continents and ocean basins.

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SECTION FOUR

The Jurassic System in Northern Canada*

HANS FREBOLD, F.R.S.C.

ABSTRACT

This paper outlines the stratigraphy, palaeogeography, and faunal composition of a number of Jurassic occurrences in northern British Columbia, the Yukon and the Canadian Arctic, based on collections made during the past few years. The sequence of events during the Jurassic is shown to differ considerably in these various regions. Faunistic and stratigraphic correlations are made with other parts of Canada, the United States, Europe, and Arctic regions other than Canada.

FOR many years little was known of Jurassic rocks over enormous regions of northern Canada. Only fragmentary information on scattered occurrences in the Yukon and the Northwest Territories, including Prince Patrick Island in the western Canadian Arctic archipelago, was available. This lack of knowledge was a serious handicap for studies on the Jurassic system in general and for the Jurassic in northern Canada in particular, as it was impossible to deduce the faunistic, stratigraphic, and palaeogeographic relationships for a vast region in which Jurassic deposits were likely to be found.

In recent years the sporadic reports of the past have given place to a veritable stream of information resulting from increased field activity by the Geological Survey of Canada and by petroleum exploration parties. The time now seems appropriate to assess some of this new information and to give some interim account of the historical geology of the Jurassic system in northern Canada, based on preliminary study of the many collections available to the author. Such is the purpose of the present paper.

Northwestern British Columbia

The following stratigraphic sequence is based on determinations of index-fossils collected in recent years by Geological Survey parties, particularly by J. G. Souther in the Telegraph Creek area.

Upper part of Upper Jurassic: probably present in part
Lower Kimmeridgian or upper Oxfordian: *Amoeboceras* div. sp. Bowser Lake area
Lower Oxfordian: *Cardioceras* (*Scarburgiceras*) cf. *cordiforme* (Meek and Hayden). Telegraph Creek area

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Callovian (?): Ammonites sp. indet. (probably Macrocephalitids). Telegraph Creek area
Lower Bajocian: *Leioceras* (?) sp. indet. Telegraph Creek area
Toarcian (?): *Pecten* sp.
Goniomya sp.
Rhynchonella sp.
Upper Pliensbachian: *Amaltheus* cf. *margaritatus* de Montfort
Arieticeras cf. *algovianum* Oppel
Arieticeras div. sp. Telegraph Creek area
Prodactylioceras (?) sp. indet.
Aegoceras (?) sp. indet. Bennett area
Sinemurian: *Arnioceras* sp. indet. Bennett area
Hettangian: *Psiloceras canadense* Frebold. Telegraph Creek area

Among these faunas that of the Pliensbachian is of particular palaeozoogeographical interest because of the presence of numerous representatives of *Arieticeras* and related genera which are characteristic of the Mediterranean Pliensbachian. Arieticeratinae occur also in the southern Yukon (see next section), where they are associated with *Amaltheus*, but are unknown in other parts of America.

In addition to the faunas already mentioned there are several other collections consisting mainly of pelecypods of unknown stratigraphic position. They may be facies equivalents of one or another of the above faunas but they may also represent stages that have not yet been proved to be present in northern British Columbia. It would be unjustified to state that stages not found so far are actually absent. It is, however, surprising that the middle Bajocian which is widely distributed in parts of Western Canada has not yet been found.

As indicated in the geological map of the Stikine River area, Cassiar district (Geological Survey of Canada, Map 9-1957), the Jurassic rocks of this region consist of rapidly changing facies. In the Lower and Middle Jurassic the rocks are reported to consist of conglomerates, greywackes, grits, siltstones, and shales; in the Upper Jurassic, shales, argillites, greywackes, conglomerates, chert, tuff, and even some coal occur. The stratigraphic position of the coal beds in relation to the other rocks is not known.

Southern Yukon

Fossils of Jurassic age are known from the Laberge series which is present in various parts of the southern Yukon. On the basis of small fragments, in a very unsatisfactory state of preservation, and poor imprints of ammonites found in shaly parts of the Laberge series in the Whitehorse district, S. S. Buckman (3, p. 21) states that strata of the lower Inferior Oolite (Middle Jurassic) down to the middle Lias (middle part of Lower Jurassic), with some gaps, are present. The revision of this material, which has not yet been described, reveals that specimens placed by Buckman into the following genera have to be considered as indeterminable: *Pleydellia*, *Dumortieria*, *Phlyseogrammoceras*, *Grammoceras*, *Haugia*, *Harpoceras*, and *Elegantulio-*

ceras. Genera actually present in this collection are *Prodactylioceras*, *Amaltheus*, *Arieticeras*, and *Pseudogrammoceras* which, as already stated by Buckman, belong to the middle and upper Lias respectively.

Another fauna which was found in the Laberge map-area (2, p. 15) was described by Lees (10). It contains ammonites, belemnites, and pelecypods. The ammonites were described as cf. *Psiloceras erugatus* Bean which is actually indeterminable, and *Arnioceras* n. sp. near *humboldti* Hyatt.

Among the pelecypods is a large, coarse-ribbed new *Pecten* (listed by Lees (10), p. 23, as *Lima* (*Ctenostreon*)). *Arnioceras* determines the age of this part of the Laberge series as Lower Jurassic, as stated by Lees. More precisely the Sinemurian stage is indicated.

Well-preserved specimens of a new species of *Arnioceras* were found in the Laberge conglomerate of Atlin district and Wheaton area. These *Arnioceras* indicate the presence of Sinemurian.

A fairly well-preserved middle Lias (Pliensbachian) fauna was recently found by J. O. Wheeler between Idaho Hill and Mount Bush in the Whitehorse map-area. It consists of *Amaltheus* cf. *margaritatus* de Montfort and various species of the genus *Arieticeras*. These two genera which are known to be associated, particularly in southern France and Italy, were also found in northern British Columbia (see p. 28).

The Jurassic sequence in the southern Yukon is as follows:

Upper Jurassic and most of Middle Jurassic: not indicated by fossils.
Lowermost Bajocian: probably present
Toarcian: *Pseudogrammoceras* sp. Whitehorse district
Upper Pliensbachian: *Amaltheus* cf. *margaritatus* de Montfort
Arieticeras div. sp.
Prodactylioceras sp. indet. Whitehorse district
Sinemurian: *Arnioceras* sp. Atlin district, Wheaton area, Laberge area.

Arctic Coast

Jurassic deposits are widely distributed in the Canadian Arctic coast region. The westernmost occurrence is on the Firth River, thirty-five miles east of the International Boundary. The ammonites collected in this area were determined by S. S. Buckman (12, pp. 14 A, 15 A) as Cadoceratids or Pseudocadoceratids which indicate a Callovian age. Unfortunately, the whereabouts of this collection is unknown.

Another fauna collected on Black Mountain in the Mackenzie River delta contains according to Stanton (12, pp. 15 A, 16 A) *Aucella* cf. *fischeriana* (d'Orbigny) and the age of the beds concerned was considered to be "Upper Jurassic or Lower Cretaceous, more probably the former." This collection could not be located.

Since 1946 many fossils have been collected in the Richardson Mountains by field parties of the Geological Survey of Canada and a number of oil companies. Preliminary determinations of these fossils, which will be de-

scribed in detail in other papers and which include such of the Lower Jurassic discovered by Jeletzky in 1955, establish the presence of the following sequence:

Upper part of Upper Jurassic: poorly preserved Aucellas of possibly Portlandian and Kimmeridgian age.
Lower Kimmeridgian or upper Oxfordian: *Aucella* aff. *concentrica* (Sowerby)
Callovian: *Cadoceras* div. sp.
Arcticoceras sp.
Bathonian: *Arctocephalites ellipticus* (Spath)
Arctocephalites aff. *nudus* (Spath)
Arctocephalites n. sp.
Toarcian: *Pseudolioceras* sp. indet.
Sinemurian: *Echioceras* sensu lato sp. indet.
Oxynoticeras sp. indet.
Arctoasteroceras jeletzkyi gen. et sp. nov.

In contrast to the southern Yukon, the middle part of the Lower Jurassic (Pliensbachian) has not yet been demonstrated in the Canadian Arctic coast region. It is not possible yet to decide whether these and other missing beds were not deposited in this region or whether they have not yet been found.

Canadian Arctic Islands

Previous to 1956 the knowledge of the Jurassic system on the Canadian Arctic islands was very restricted. A few ammonite fragments from Prince Patrick Island originally described by Haughton (8) and rediscussed by Neumayr (11, p. 85) were considered to be of Toarcian or early Bajocian age. From the same island Imlay (9) figured *Harpoceras*, some *Dactylioceras*, and *Ludwigella*(?).

Since 1955 various field parties of the Geological Survey of Canada have worked in the Canadian Arctic and many fossils were collected on which age determinations and correlations of the various beds concerned can be based. The following account deals with two main regions in which comparatively complete sections were found: (*a*) Prince Patrick Island; (*b*) Axel Heiberg and Ellesmere islands. Occurrences on other islands are mentioned in the discussion of these two regions.

(*a*) *Prince Patrick Island*

On the basis of stratigraphic information and a carefully collected sequence of fossils by E. T. Tozer (13) the following subdivision of the Jurassic strata of Prince Patrick Island was established by the author (7). A few changes or additions based on recently collected material have been made.

Upper Jurassic: non-marine
Lowermost Callovian: *Arcticoceras* sp.
Bathonian: *Cranocephalites vulgaris* Spath

Arctocephalites ? sp. indet.
Cylindroteuthis sp.
Inoceramus sp. indet.
Pecten sp. indet.

Middle Jurassic, no exact age determination, but younger than lower Bajocian and older than beds with *Arcticoceras*:
Arkelloceras tozeri Frebold
Arkelloceras mclearni Frebold
Inoceramus lucifer Eichwald
Inoceramus sp.
Pecten (*Camptonectes*) sp.

Lower Bajocian: *Leioceras opalinum* (Reinecke)
Pseudolioceras m'clintocki (Haughton)
Belemnites sp. indet.
Goniomya cf. *v-scripta* (Sowerby)
Oxytoma septentrionalis (Haughton)
Gresslya aff. *abducta* (Phillips)

Toarcian: *Pseudolioceras* aff. *compactile* (Simpson)
Harpoceras cf. *exaratum* (Young and Bird)
Catacoeloceras spinatum Frebold
Dactylioceras commune (Sowerby)
Belemnites sp. indet.
Cucullaea sp.
Protocardia striatula (Phillips)
Pleuromya aff. *simplex* Warren
Gresslya rotundata (Phillips)
Oxytoma sp.

The oldest Jurassic beds so far found on Prince Patrick Island belong to the Toarcian, which forms the base of the Jurassic also on other Arctic islands (Cornwall, Axel Heiberg, Ellesmere). No lower or middle Lias have yet been found. On Borden and Melville islands fossiliferous Sinemurian was recently discovered by R. Thorsteinsson and E. T. Tozer. The Toarcian is also present on these islands and on Mackenzie King Island.

The interesting lower Bajocian *Leioceras opalinum* fauna of Prince Patrick Island occurs also on Melville Island; slightly younger beds may be present on Cameron and Axel Heiberg islands.

No attempt has been made to determine the exact age of the new Middle Jurassic genus *Arkelloceras* on the basis of its possible phylogenetic position. Such attempts are always based on a hypothesis and will not guarantee factual results. It is hoped that the age of this genus will be clarified by further discoveries in the field.[1]

The Bathonian beds with *Cranocephalites* have not been found on other Canadian Arctic islands but slightly younger beds (with *Arctocephalites*) are present in the Canadian Arctic coast region (see p. 30).

[1]During the discussion of this paper Dr. Westermann suggested a Callovian age of this genus judging on a poorly preserved sutureline figured by the author (7, Pl. 11, Fig. 2a).
Recent field work by Dr. Thorsteinsson and Dr. Tozer has shown that in Prince Patrick Island the stratigraphic position of *Arkelloceras* is sixty feet below the lowermost Callovian *Arcticoceras* bed and sixty feet above the Lower Bajocian *Leioceras opalinum* bed. Therefore, a Callovian age of *Arkelloceras* is out of the question.

Callovian beds with *Cadoceras* are not found in Prince Patrick Island but are present on both Cornwall and western Axel Heiberg islands.

The non-marine development of the Prince Patrick Island Upper Jurassic is in agreement with conditions on other Canadian Arctic islands but on Axel Heiberg marine intercalations representing parts of the Oxfordian, Kimmeridgian, and Portlandian are present. On Ellesmere Island marine Portlandian was found and in addition ammonite faunas of the Berriasian, which are also present in Axel Heiberg Island. Marine Oxfordian with Cardioceratids was recently found by R. Thorsteinsson and E. T. Tozer on Mackenzie King Island.

(*b*) *Axel Heiberg and Ellesmere Islands*

Several collections from Axel Heiberg and Ellesmere islands were made by E. T. Tozer at Strandfjord, western Axel Heiberg, and on Fosheim Peninsula, Ellesmere Island; by J. G. Souther near Buchanan Lake, eastern part of Axel Heiberg; and by R. Thorsteinsson at Reptile Creek north of Eureka weather station, and Slidre Fjord, western part of Ellesmere Island.

On the basis of the author's determination of the fossils collected the Jurassic sequence can be subdivided as follows:

Western Axel Heiberg Island

Upper part of Jurassic: probably indicated by marine Pelecypod faunas
Callovian: *Cadoceras* sp. indet.
Toarcian: *Catacoeloceras spinatum* Frebold

Eastern Axel Heiberg Island

Berriasian (Lowermost Cretaceous): *Subcraspedites* div. sp.
Aucella cf. *terebratuloides* Lahusen
Aucella cf. *volgensis* Lahusen
Portlandian: *Dorsoplanites* sp. indet.
Camptonectes praecinctus Spath
Aucella sp.
Lower Kimmeridgian or upper Oxfordian: *Amoeboceras* sensu lato sp. indet.
Aucella sp. indet.
Rasenia ? sp. indet.
Lower Oxfordian: *Cardioceras* (*Scarburgiceras*) aff. *mirum* Arkell
Toarcian: *Dactylioceras* (?) sp. indet.

Fosheim Peninsula, Ellesmere Island

Toarcian: *Catacoeloceras polare* Frebold
Pseudolioceras ? sp. indet.

Reptile Creek, Ellesmere Island

Berriasian (Lowermost Cretaceous): *Tollia* div. sp.
Subcraspedites div. sp.
Aucella cf. *terebratuloides* Lahusen
Aucella cf. *volgensis* Lahusen
Portlandian: *Dorsoplanites* sp. indet.
Camptonectes praecinctus Spath
Aucella sp.
Oxytoma sp.

The Distribution of Jurassic Faunas in Northern Canada and Possible Palaeogeographic Conclusions

The distribution of the various Jurassic faunas and stages in northern Canada based on the preceding account is summarized in Table I and Figure 1. Figure 1 also shows the author's (6;7) view on the maximum extent of the Jurassic seas in these parts of Canada. The great advances made recently in our knowledge of the distribution of marine Jurassic faunas tempts one to draw the coastlines of various Jurassic seas; however, this temptation has been resisted at the present time because some beds, as yet missing in certain regions, may be found in the future, and palaeogeographic

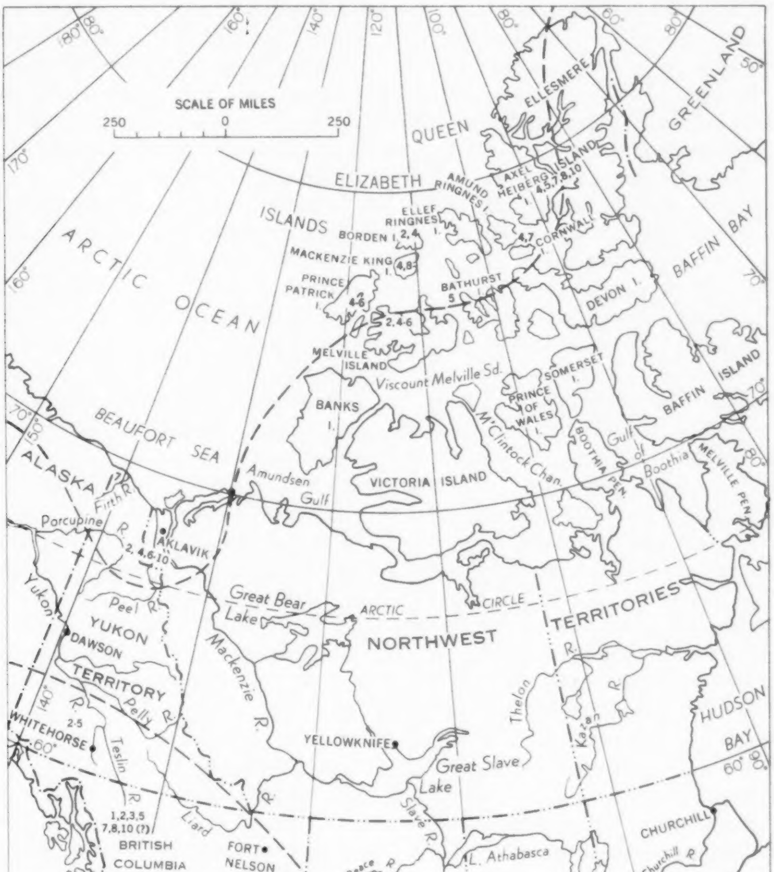

Figure 1.—Distribution of various Jurassic stages in northern Canada. Numbers correspond with numbers in column 2 in Table I. Broken lines indicate the maximum extent of marine deposition during Jurassic time.

TABLE I

SUBDIVISION AND INDEX FOSSILS OF THE JURASSIC SYSTEM IN VARIOUS PARTS OF NORTHERN CANADA*

	Stages	Northwestern British Columbia	Southern Yukon	Canadian Arctic Coast	Prince Patrick Island	Axel Heiberg and Ellesmere islands
Upper Jurassic	Portlandian (10)	no index fossils; possibly present in part	not identified	probably present; *Aucella* div. sp.	non-marine	*Dorsoplanites*
	Upper Kimmeridgian (9)	possibly present in part				?
	Lower Kimmeridgian and Oxfordian (8)	*Amoeboceras* sp. *Cardioc.* cf. *cordiforme*		*Aucella* aff. *concentrica*		*Amoeboceras*, *Rasenia*(?) *Cardioceras*
	Callovian (7)	Macrocephalitids (?)		Cadoceratids		*Cadoceras*
Middle Jurassic	Bathonian (6)	not identified not identified		*Arcticoceras* *Arctocephalites* not identified	*Arcticoceras* *Cranocephalites* *Arkelloceras*	not identified
	Bajocian (5)	*Leioceras* (?)	possibly present		*Leioceras opalinum*	*Ludwigia*
	Toarcian (4)	no index fossils; possibly present	*Pseudo-grammoceras*	*Pseudolioceras*	*Catacoeloceras*, *Pseudolioceras*, *Dactylioceras*	*Catacoeloceras*, *Grammoceras*
Lower Jurassic	Pliensbachian(3)	*Amaltheus* cf. *margaritatus*, *Arieticeras*, *Prodactylioceras*	*Amaltheus* cf. *margaritatus*, *Arieticeras*, *Prodactylioceras*	not identified	absent	non-marine
	Sinemurian (2)	*Arnioceras*	*Arnioceras*	*Oxynoticeras*	absent	
	Hettangian(1)	*Psiloceras canadense*	doubtful	not identified	absent	

*Numbers in column **2** correspond with numbers on map (Figure 1).

conclusions based on the known distribution of the beds concerned may prove to be premature. However, some statements can be made: in the Canadian Arctic the Sinemurian sea invaded at least a part of the Arctic coast region, Borden Island and a part of Melville Island. Other Arctic islands were covered by the sea not earlier than in Toarcian time. The Toarcian transgression reached also the area of the Richardson Mountains. Deposits of lower Bajocian seas are known from both eastern and western parts of the Arctic archipelago but not from the Arctic coast region. At least Prince Patrick Island and a part of Melville Island were covered by the sea during the *Arkelloceras* time. The sea with *Cranocephalites*, *Arctocephalites*, and *Arcticoceras* invaded a part of Melville Island, Prince Patrick Island, and the area of the Richardson Mountains. No traces of this sea have been found so far on the main part of the Arctic archipelago. The Callovian sea (with *Cadoceras*) is known to have covered parts of the Arctic islands and the Arctic coast region and this sea may prove by further findings to be one of the more extensive ones in the Canadian Arctic. Upper Jurassic transgressions younger than that of the Callovian are known to have invaded the Arctic coast region, Mackenzie King Island, and the eastern part of the Arctic archipelago (Axel Heiberg and Ellesmere islands). In the Arctic Coast region poorly preserved though rich *Aucella* faunas indicate marine conditions in Oxfordian, Kimmeridgian, and Portlandian times. On Mackenzie King Island Cardioceratids of probably late Oxfordian age occur, while on Axel Heiberg and Ellesmere islands Ammonites and Aucellas prove the presence of at least temporary transgressions during the early and late Oxfordian, the early Kimmeridgian, and the Portlandian. Here marine conditions continued during the Berriasian (the earliest Cretaceous) which is indicated by rich Ammonite and Aucella faunas. Marine Middle and late Upper Jurassic is hitherto unknown from other Canadian Arctic islands and seems to be replaced by non-marine deposits.

In summary, it can be stated that in the Canadian Arctic a number of transgressions of changing extent took place in Jurassic times and that regions of comparatively complete marine development were the eastern parts of the islands and parts of the Arctic coast region.

In the southern Yukon and northwestern British Columbia the first Jurassic transgression took place in Early Jurassic times (Hettangian and Sinemurian). Another sea invaded during the Pliensbachian bringing with it an abundance of Arieticeratids hitherto known as a predominantly Mediterranean faunal element. Marine deposition is also established for the southern Yukon during the Toarcian and perhaps the earliest Bajocian but after this time the sea retreated from this region. In northwestern British Columbia Middle Jurassic or Callovian transgressions have not yet been indicated with certainty, although beds belonging to the stages concerned may be found in the future. Marine conditions were, however, present during the early and late Oxfordian and perhaps early Kimmeridgian. The

beds concerned contain locally rich faunas of Cardioceratids. As no distinctive fossils of late Upper Jurassic age have yet been found in this part of British Columbia the events during this time are unknown, but at least temporary marine deposition seems to have taken place.

In previous papers (6;7) it is indicated that the Jurassic seas of British Columbia were connected with those in the present day Rocky Mountain, Foothills, and Plains regions but an assumed seaway through the Mackenzie River region connecting the Arctic Jurassic seas with those in British Columbia and the southern Yukon was not found to be substantiated by any facts.

Comparisons with Spitsbergen and Greenland

Some of the Jurassic faunas recently discovered on the Canadian Arctic islands show close relationships with faunas in Spitsbergen and east Greenland. The author (7) has already pointed out that even the lithological facies of the Prince Patrick Island Toarcian (phosphatic nodules) is also present in Spitsbergen.

Particularly close relationships seem to be present between the Upper Jurassic faunas of Axel Heiberg and Ellesmere islands and those in Spitsbergen and parts of east Greenland, but, unfortunately, most of the Canadian faunas concerned are very poorly preserved and do not permit detailed comparisons. It is highly desirable to have better material collected in the Upper Jurassic of Axel Heiberg and Ellesmere islands. However, the fossils hitherto collected on these islands show that the following east Greenland or Spitsbergen subdivisions seem to be present in the eastern part of the Arctic Islands: lower Oxfordian (*Cardioceras*), upper Oxfordian (*Rasenia*, *Amoeboceras*), and uppermost Kimmeridgian or lower Portlandian (*Dorsoplanites*, *Camptonectes praecinctus* Spath). In addition to these similarities of Upper Jurassic faunas in the regions compared, the well-preserved Berriasian (lowermost Cretaceous) faunas of Axel Heiberg and Ellesmere islands are also represented in parts of the Barents Shelf and in east Greenland. Two faunas belonging to this stage are found: a lower one with representatives of the genus *Subcraspedites* and an upper one with *Tollia*. These Upper Jurassic and Lower Cretaceous similarities indicate that the eastern part of the Canadian Arctic islands belongs to the same fauna province as east Greenland and the Barents Shelf and that the course of events during these times followed the same lines in all three regions concerned.

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TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
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SECTION FOUR

Teaching the Geological Sciences

G. B. LANGFORD, F.R.S.C.

ABSTRACT

Geology is a science and teachers in this discipline must adhere to the methodology of the basic sciences. Purely descriptive subjects have their place in a curriculum. Unless they are built on observation, interpretation, and induction, they are not sciences. The manner in which outside influences affect curricula is touched upon.

A DISCOURSE on this topic would be meaningless if it did not state the author's conception of that almost indefinable term "science." A most satisfactory statement, and one that has governed my thinking, is given in the *Cambridge Encyclopaedia*. "Science may be said to consist in the classification of facts, and the recognition of their sequence and relative significance. This at any rate is the function of science, and it can at once be seen that the term has a far wider meaning than that popularly given it. It includes all forms of systematized thought; therefore it is not facts nor even useful knowledge which forms science, but the method in which any facts are dealt with." Under the heading "Scientific Method," the same encyclopaedia has the following observation: "Science is primarily concerned with the collection, arrangement and classification of the knowledge about the world around us. It is subdivided for convenience into subjects like astronomy, physics, chemistry, biology, geology, etc., although there is no hard and fast line between any two so-called branches of science."

Geology is a comparatively new arrival in the realm of the sciences. As such it had to establish its right to a place in this august company. Complete acceptance could only be granted when the newcomer had demonstrated that its scientific philosophy and methods were comparable to those of the others, and because the workers in geology were well versed in the basic sciences and could communicate with fellow scientists in their own languages.

The great progress made in geologic thought during the past century was, in large measure, owing to a number of individuals trained in the other basic sciences, who turned their attention to natural philosophy.

The geological sciences are, and always will be, based on mathematics, physics, chemistry, and biology, which are usually thought of as basic sciences. This dependency does not need any justification or clarification. The geological sciences were built from them in a series of steps or orders. The first order, arising directly from the basic sciences, includes such subjects as crystallography, mineralogy, palaeontology, geochemistry, and geophysics. The second order, in turn, would draw some of its substance from the basic

sciences, and some from the first-order subjects. Here belong physical geology, petrology, historical and stratigraphic geology, and so on. A third order would include structural geology, sedimentation, mineral deposits, and other applied aspects of geology. It is possible to visualize other orders being added to these.

The presentation of geological subjects as a series of steps or orders is not to be thought of as a proposed classification; it is intended to indicate how new subjects arise out of established ones. I believe that teachers should make their students aware of this, for it both puts the subject in its proper perspective and impresses on the student other scientific fields prerequisite to the one currently being studied.

Teaching the first order of subjects must be based on a rigorous scientific approach which calls on the students to use both their knowledge of the appropriate basic science and the principles of scientific methods. Teachers in these subjects must be well trained in the other basic sciences. They must use them in the development of their geologic science and, equally important, they must always conform to the recognized principles of scientific procedure.

Teachers and students of the second- and third-order subjects must be entirely conversant with the appropriate preceding subject. They must also maintain sufficiently close contact with the basic sciences to be aware of new developments, and to be capable of understanding any geological implications in them.

The subjects in each of these orders are new disciplines. They may be rigorously scientific, following the pattern of their ancestry, or they may become increasingly descriptive. Unless great care is taken, the principles and philosophies of the basic sciences which constitute the "scientific method" may be supplanted by loose thinking, often characteristic of descriptive subjects, when induction and deduction give way to inference and speculation.

There is a *modus operandi* common to all branches of science. It is observation, interpretation, induction, and experimentation. In the geological sciences it is not always possible to do experimental research, and to the extent that this is so, this branch of science must deviate from the accepted pattern in its approach to its problems. The necessity for such deviations should not become a license to adopt a less rigorous adherence to the other scientific methods; it should be an incentive to keener observations, more careful interpretations, and more searching deductive reasoning. A scientist working under such conditions should realize that he is handicapped and that his problems will be made more difficult.

In the geological sciences the use of descriptive methods and material is frequently necessary and in some circles geology is for that reason discounted as a science. Unfortunately, the word "descriptive" is used in many ways, some of which have a scientific connotation while others have not. If the descriptive material lends itself to treatment by scientific methods, and is so

treated, then it belongs in the realm of science. When, however, the descriptions are merely discourses or statements of experience, they are not sciences. Teachers of geology should not indulge in any fuzzy thinking on the nature of the descriptive material they use. The extent to which they use non-scientific methods and material in their courses will determine whether or not the course should be classed as a science. It is unwise to use such modifying terms as "descriptive science" for they carry the implication that there are approaches to science other than by a rigorous application of the methods mentioned earlier.

Even the unscientific descriptive topics have a place in teaching geology. They are often the leaven that raises a lecture from the level of tediousness to that of enjoyment. The cultural value of geology owes much to the fact that it may be presented in such a form. There are pitfalls associated with descriptive topics, however, of which teachers should be constantly aware. Much of what is descriptive, even if it is amenable to sound scientific analysis, cannot be tested by experimentation, and there are situations in which observations are limited. As a result geology suffers from the formulation of so-called hypotheses when observational and experimental evidence is not available or is inadequate. An outstanding scientist may achieve success under such conditions because of his training and experience in other scientific pursuits, but if a student is brought up in such an atmosphere he never acquires a true concept of a science and will go forth and practise pseudo-scientific methods under the guise of geology.

Another pitfall appears when students are introduced to geology by a course that has a large unscientific descriptive content. Under an elective curriculum the students may take a series of such courses, thinking that they are being trained as geologists, and neglect the other sciences in the mistaken belief that they are not necessary. Such students even apply for admission to graduate schools and are amazed and disappointed when told that they must spend two or three years learning the science of geology as well as physics, chemistry, and so on, before they will be qualified to undertake graduate studies.

All branches of science are forever expanding and ramifying. At present these processes are going forward at an increasing rate and there is some danger that we may reach a point where we cannot see the woods for the trees. We all realize that in this age of specialization men must work in restricted areas which seem to get smaller and smaller as the worker digs deeper and deeper. It is inevitable that this should be so, for there is no other manner in which knowledge can advance. However, as teachers of science we must not confuse areas in which people work with subjects which we must teach. We must resist the pressure to add this or that topic to our courses in order that the students' knowledge will be more highly specialized when they graduate. There is a danger that curricula will become crowded with specialized and practical courses which attempt to prepare the student to step into a specific niche when he leaves school. This is a form of

Deweyism which will result in the graduation of technicians and not scientists.

Even if the universities resist the requests for more specialized courses, there are ways in which events outside the universities have an unfortunate effect on what goes on inside. Undergraduates become aware of what will be demanded of them on graduation, and their attitude to their studies is governed accordingly. It is therefore of some interest to take a critical look at what geological graduates do. We all know that some become scientists in government agencies, some follow academic careers, a few are employed as scientists by commercial organizations, while the majority are employed by the mining and petroleum industries. But what are their duties, especially those in industry?

In the mining industry there is a great waste of geological talent. While there are a few—very few—geologists who have done, and are doing, scientific work of a high order, and who have been responsible for some of the outstanding developments of recent years, nevertheless it is true that geologists in this field use very little of their geological knowledge. Those employed in exploration, if in junior roles, are routine samplers and mappers; if in senior roles they are chiefly administrators or expediters. Those who work in mines are essentially geological book-keepers. None of these men have duties that necessitate four years of university training in geology, let alone an added three or four years of post-graduate work. There are few of their geological duties that could not be done by well-trained technicians. For the most part they do not have the facilities or the time for scientific work. In the petroleum industry there is much less misuse of talent for here geological staffs are doing work of a scientific nature.

Students realize that they will not need a great fund of geological knowledge. Even if they did not perceive this while doing summer work they are made aware of it on graduation, for they can get jobs with exploration companies whether they take geological courses or other courses in which there is a minimum of geological content. They realize that scholarship and scientific achievement mean little in getting a job. They also see that the practising geologists, with few exceptions, are not doing geological work of a very profound nature. The result of this is a logical one: the students become more interested in a degree than in the knowledge that should go with it. Teachers are up against a formidable task in trying to inspire such students to follow scientific pursuits.

In recent years we have seen another development that has given scientific development a setback. The shortage of field men has led exploration companies to employ university staffs for summer work. Seldom have these men been called upon to use their highly specialized knowledge. In fact, it is unusual for men in this type of work to be able to find time or encouragement for any scientific investigations. Consequently we find that the teachers also are neglecting their science.

Teachers of geology, in company with teachers of other sciences, must divide their time and energy between instruction and research, and even under normal conditions it is difficult to find sufficient time to do justice to both. The environment in which we have operated in recent years has slowed down scientific development in geology, and another serious problem lies ahead—increasing student enrolment. It is altogether likely that greater demands will be made of professors in the future than at present. There can be only one result: university staffs will not have the time to deal adequately with all their duties and responsibilities, and under such conditions it usually happens that research work is postponed. As teachers we must be ever on our guard and should take every step necessary to cast off those influences which mitigate against the progress of the geological sciences.

The science of geology has advanced in a remarkable manner over the past century, and an even greater development lies ahead as we learn to apply the new developments in other sciences to geological problems, and as more workers delve more deeply into our own fields. The present state of geological knowledge is the result of the efforts of generations of devoted scientists, and future developments depend on the extent to which the coming generations devote themselves to the science.

I have endeavoured to set down some of the problems of the teachers of geology, and to enumerate some of the forces that are slowing down development of the scientific side of our subject. All of these have arisen in an innocent but none the less effective manner, and unless we recognize and overcome them they will bring about an unfortunate deterioration of geology as a science. Most teachers of geology today have had a sound scientific training. If our students are so trained they will in turn pass on a strong and vigorous science to succeeding generations. If, on the other hand, they are not well-trained scientists they cannot pass on what they do not possess, and so scientific deterioration begins.

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SECTION FOUR

Brachiopod Zones of the Mount Head and Etherington Formations, Southern Canadian Rockies*

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ABSTRACT

Brachiopod assemblages from the Mount Head (Meramecian) and Etherington (Chesterian) formations are arranged according to zones. Zones recognized are the *Spirifer bifurcatus*, *Echinoconchus biseriatus*, and *Girtyella indianensis* of lower, middle, and upper Mount Head, respectively; the *Gigantoproductus brazerianus* zone of uppermost Mount Head and lowermost Etherington; and the *Dictyoclostus parvus*, *Punctospirifer transversa* and *Diaphragmus cestriensus* zones of lower, middle, and upper Etherington, respectively. A possible higher zone, the *Spirifer matheri*, found at one locality suggests that the uppermost Etherington may be, in part, Pennsylvanian.

Type Tunnel Mountain formation is thought to be Pennsylvanian in age, not Chesterian as commonly asserted.

INTRODUCTION

PERMO-CARBONIFEROUS strata of the southern Canadian Rockies consist, in ascending order, of the Banff formation, Rundle group, and Rocky Mountain group. The Banff formation, an argillaceous unit, spans Kinderhookian and part of Osagean time. The overlying Rundle group is a predominately carbonate sequence consisting of the Livingstone formation (s. l.) of Osagean age; the Mount Head, of mainly Meramecian age; and the Etherington formation, of mainly Chesterian age. The Rundle is followed by a relatively unfossiliferous succession termed the Rocky Mountain "group." The subdivision and dating of this latter unit have been subject to various interpretations. The Rocky Mountain at the type area near Banff was divided into the Tunnel Mountain formation[1] and the Norquay forma-

*The writer wishes to extend his gratitude to the officials, particularly Dr. A. D. Baillie, of The British American Oil Company, Calgary, whose help and encouragement contributed greatly to the completion of this study. Dr. P. S. Warren and Dr. C. R. Stelck, of the University of Alberta, have given valuable criticism during this project.

[1]The name "Tunnel Mountain formation" has been applied to carbonates herein called Etherington formation. Raasch (9) dated these carbonates on Mount Rae Chesterian and correlated most of them with type Tunnel Mountain. He therefore applied the name Tunnel Mountain formation to these carbonates even though they belonged to lithofacies different from the type. The term Rocky Mountain formation was raised to group status and restricted to beds of Permian age so that it contained the Norquay and Storm Creek formations (10). The Tunnel Mountain was thereby excluded from the group and placed in the Rundle. The advisability of placing the Tunnel Mountain in the Rundle group should be questioned. The present investigation suggests that Raasch's (9;10) Tunnel Mountain formation of Mount Rae (= Etherington of this paper), actually correlates

tion. Warren (13) considered the Tunnel Mountain to be Pennsylvanian and the Norquay Permian. Raasch (9;10) interpreted the Tunnel Mountain as Chesterian and the Norquay as Permian. The Storm Creek formation with its type area some forty-five miles southeast at Mount Rae has also been placed in the Rocky Mountain group (9;10) but its stratigraphic position with respect to type Rocky Mountain is at present in doubt (cf. 9, 10 with 8).

This paper is concerned with brachiopod zonation of the Upper Mississippian Mount Head and Etherington formations. Eight zones are recognized. Delineation of these is based upon a detailed study of fourteen sections scattered from near the International Boundary to the Red Deer River area. In addition supplementary information has been gained from oil company collections from both the southern Rockies and the Peace River Rockies.

Brachiopod zones are tabulated on Figure 1; and are compared on Figure 2 with zones of other workers. Position of the zones is shown for two well-known sections in Alberta. One is Mount Rae (sometimes called Storm Creek) at Highwood Pass; the other is Tunnel Mountain at Banff. The former section has been described in detail by Raasch (9); the latter by Beales (1). Mount Rae contains an excellently exposed and fossiliferous section of both the Mount Head and the Etherington formations. The Tunnel Mountain section is almost as well exposed but not as fossiliferous, particularly in equivalents of the Etherington formation. Supplementary information for these and nearby sections has been given by Kindle (7), Shimer (11), Warren (12), Douglas (5), Crickmay (4), Norris (8), and Bostock, Mulligan, and Douglas (2).

Most of the brachiopod zones postulated are fossiliferous only from the Bow River valley southward. North of here strata tend to be unfossiliferous although representatives of the *Echinoconchus biseriatus*, *Gigantoproductus brazerianus*, *Dictyoclostus parvus*, and *Punctospirifer transversa* zones have been recognized at intervals as far north as the Peace River area.

Until recently little information was available on Upper Mississippian zonation for the Canadian Rockies. Papers by Shimer (11), Warren (12), and Brown (3) formed the basis for our knowledge of the palaeontology. Brown alone paid attention to zonation but his studies were concerned mostly with Lower Mississippian. Raasch (9) gave the first systematic description of Upper Mississippian faunal zones. From his studies of the very fossiliferous section at Mount Rae he recognized five brachiopod zones. In 1955, at the regional meeting of the American Association of Petroleum Geologists at Jasper, Harker and Raasch presented their views on Carboniferous and Permian zonation (6). Five zones embraced the Mount Head and Etherington formations. The Mount Head was zoned by corals, the

both temporally and in large part lithologically with the uppermost 300 feet of type Rundle. Thus type Tunnel Mountain must be excluded from the Rundle by reason of its lithology and from the Rocky Mountain (restricted) because of its age. The reader is referred to Norris (8) for possible interpretations of Rocky Mountain (s. l.) stratigraphy.

ETHERINGTON FORMATION	Spirifer matheri zone	Spirifer matheri, S. cavecreekensis(r), Composita subquadrata(r).
	Diaphragmus cestriensis zone	Diaphragmus cestriensis, Dictyoclostus coloradoensis?, Echinoconchus rodeoensis?(r), Linoproductus ovatus(r), Orthotetes kaskaskiensis(r), Spirifer cavecreekensis, S. leidyi(r), Composita subquadrata, Eumetria vera.
	Punctospirifer transversa zone	Punctospirifer transversa, Echinoconchus rodeoensis?,Linoproductus ovatus, Orthotetes kaskaskiensis, Spirifer arkansanus, Dielasma shumardanum.
	Dictyoclostus parvus zone	Dictyoclostus parvus, D. inflatus, Echinoconchus rodeoensis?(r), Linoproductus ovatus(r), Orthotetes kaskaskiensis(r), Gigantoproductus brazerianus(r), Spirifer leidyi, Composita trinuclea(r), Girtyella brevilobata, Dielasma shumardanum(r).
	Gigantoproductus brazerianus zone	Gigantoproductus brazerianus.
MOUNT HEAD FORMATION	Girtyella indianensis zone	Girtyella indianensis, Pugnoides parvulus, Gigantoproductus brazerianus(r), Spirifer pellaensis(r), Composita deltoides(r).
	Echinoconchus biseriatus zone	Echinoconchus biseriatus, Dictyoclostus sp., cf. D. tenuicostus, Productella indianensis, Rhynchopora? banffensis, Spirifer bifurcatus(r), Girtyella turgida.
	Spirifer bifurcatus zone	Spirifer bifurcatus, Dictyoclostus altonensis, Linoproductus ovatus(r) Spirifer pellaensis(r), Composita trinuclea(r).

FIGURE 1.—Upper Mississippian brachiopod zones and contained species. Rare and undiagnostic species are followed by "r."

Etherington by brachiopods. Modified results of their investigations are in the *Allan Memorial Volume* of the American Association of Petroleum Geologists.

Mount Head zones postulated by Raasch (9) and Harker and Raasch (6) appear valid but discrepancies exist between the zonation of the Etherington formation given by these authors and that given by the present writer. The latter finds that the long-ranging *Spirifer leidyi*, their zone fossil for upper Etherington, is more common within their *Spirifer increbescens* zone (lower, and part of middle Etherington) except at Mount Rae itself.

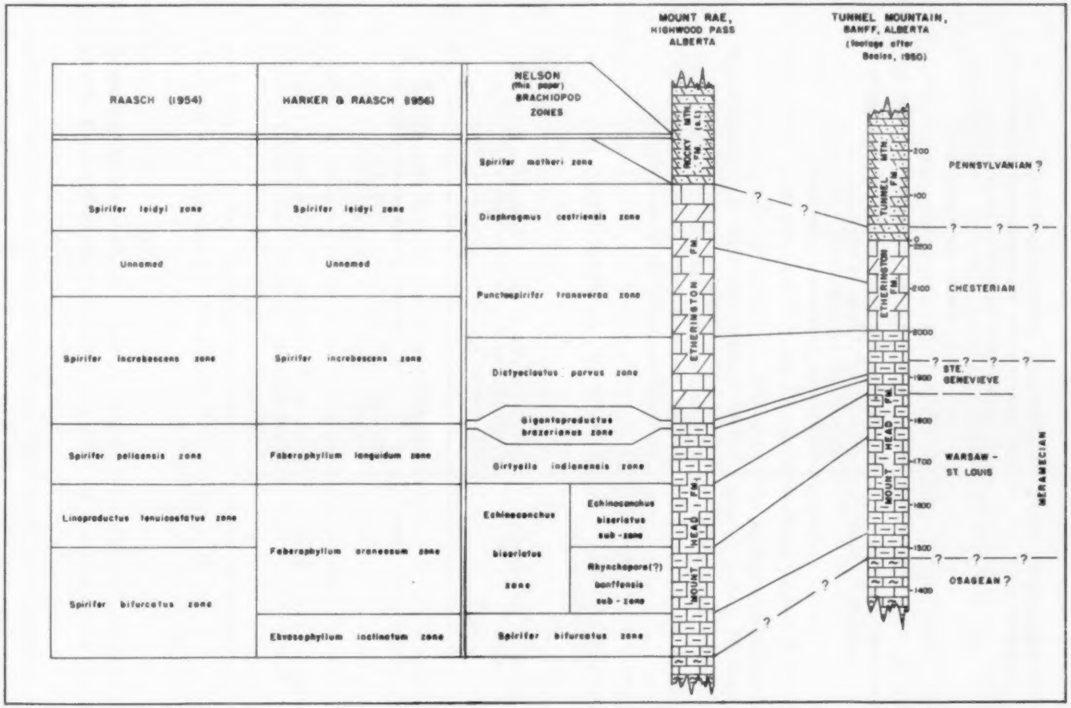

FIGURE 2.—Previous and present faunal zonations of the Mount Head and Etherington formations.

"*Spirifer increbescens*" (= ?*Spirifer cavecreekensis* of this paper), their zone fossil for lower and part of middle Etherington, is more common in upper Etherington (see *Diaphragmus cestriensis* zone).

Dating of the Brachiopod Zones

The *Spirifer bifurcatus* and *Echinoconchus biseriatus* zones cannot be placed accurately with respect to type Mississippian of the upper Mississippi River valley region. Some species, long-ranging in type Mississippian, are short-ranging in these two Mount Head zones, and vice versa. Species from the two zones, however, are characteristic of parts of the Warsaw, Salem, and St. Louis formations of type section. The *Girtyella indianensis* zone contains few diagnostic species but the zone fossil is characteristic of the Ste. Genevieve limestone. *Gigantoproductus brazerianus*, the zone fossil for uppermost Mount Head and lowermost Etherington, is restricted to western North America and cannot be dated with respect to type Mississippian.

The *Dictyoclostus parvus* zone of lower Etherington may be upper Meramecian (Ste. Genevieve) or lower Chesterian. *Dictyoclostus parvus*, *Spirifer leidyi* and *Girtyella brevilobata* occur in both. *Dictyoclostus inflatus* and *Dielasma shumardanum* are Chester species, while an associated colonial coral *Lithostrotion genevievensis* Easton is a Ste. Genevieve species. The *Punctospirifer transversa* and *Diaphragmus cestriensis* zones are Chesterian.

Spirifer matheri, the zone fossil for the *Spirifer matheri* zone, is Pennsylvanian. This dating for the zone should be considered tentative because *S. matheri* of this paper may be a variant of the Mississippian *S. cavecreekensis* adapted to different environmental conditions.

Brachiopod Zones

Spirifer bifurcatus Zone

This zone, usually spanning the lower 100 feet of the Mount Head formation, contains *Spirifer bifurcatus* Hall, *Linoproductus altonensis* (Norwood and Pratten), and rare, less diagnostic *Linoproductus ovatus* (Hall), *Spirifer pellaensis* Weller, and *Composita trinuclea* (Hall).

The zone is fossiliferous at Mount Rae but not so at Tunnel Mountain. It probably occurs in the latter section in the interval around 1,480 feet above the base of the Rundle group. At Lake Minnewanka it is present in Crickmay's (4) bed 11 of the Rundle. Brown's (3) "*Spirifer* n. sp. A. faunule" of the Greenock formation of Jasper probably belongs in this zone or in the one above.

Echinoconchus biseriatus Zone

Two sub-zones for the *Echinoconchus biseriatus* zone are called the *Rhynchopora* (?) *banffensis* and *Echinoconchus biseriatus* sub-zones.

The *Rhynchopora* (?) *banffensis* sub-zone generally extends through about 150 feet of beds in the Mount Head formation and contains the diagnostic *Rhynchopora* (?) *banffensis* Warren, *Productella indianensis* (Hall), *Girtyella turgida* (Hall), and the less diagnostic *Echinoconchus biseriatus* (Hall), *Dictyoclostus* sp., cf. *D. tenuicostus* (Hall), and *Spirifer bifurcatus* Hall. Position of the sub-zone at Mount Rae and Tunnel Mountain is shown on Figure 2.

The *Echinoconchus biseriatus* sub-zone contains *Echinoconchus biseriatus* (Hall) and *Dictyoclostus* sp., cf. *D. tenuicostus* (Hall). This sub-zone occupies strata above the upper ranges of diagnostic species for the *Rhynchopora* (?) *banffensis* sub-zone and below the lower ranges of species in the *Girtyella indianensis* zone. The sub-zone is fossiliferous and extends through about 150 feet of beds at Mount Rae. It has been tentatively identified at 1,845 feet above the base of the Rundle group at Tunnel Mountain.

Girtyella indianensis Zone

Fossils diagnostic of the *Girtyella indianensis* zone are *Girtyella indianensis* (Girty) and *Pugnoides parvulus* Girty. Less diagnostic species are *Gigantoproductus brazerianus* (Girty), *Spirifer pellaensis* Weller, and *Composita deltoides* Hernon.

The zone occupies the upper 100 feet of the Mount Head formation on Mount Rae but has not been positively identified on Tunnel Mountain. The relative closeness of the *Gigantoproductus brazerianus* to the *Echinoconchus biseriatus* zone at Tunnel Mountain, compared with the corresponding interval at Mount Rae, suggests that strata contained by the *Girtyella indianensis* zone are either absent at Tunnel Mountain or condensed. Relationships similar to those at Tunnel Mountain occur at Mount Norquay, Lake Minnewanka, and to the north.

Gigantoproductus brazerianus Zone

This zone, the most persistently fossiliferous and easily recognizable one in the Mississippian of the Canadian Rockies, contains only *Gigantoproductus brazerianus* (Girty) as the diagnostic brachiopod. South from Mount Rae the species generally occupies ten to fifteen feet of beds in uppermost Mount Head and/or lowermost Etherington. At Tunnel Mountain it occurs within the Mount Head formation at 1,905 feet above the base of the Rundle, while at Lake Minnewanka it is present in uppermost Rundle immediately below the Rocky Mountain group.

Care should be taken in identifying the zone, for the diagnostic *Gigantoproductus brazerianus* is known to range into the lower part of the overlying *Dictyoclostus parvus* zone and through most of the underlying *Girtyella indianensis* zone. Its occurrence in these two zones, however, is very rare. Typically the species occurs in its named zone as densely packed, almost coquinoid masses of shells in beds generally six inches or less thick. In nearly

all sections examined, thinly interbedded green bentonitic shales occur near the top of the zone and extend into the younger *Dictyoclostus parvus* zone.

Dictyoclostus parvus Zone

Dictyoclostus parvus (Meek and Worthen), *D. inflatus* (McChesney), and *Girtyella brevilobata* (Swallow) are diagnostic of this zone. *Spirifer leidyi* Norwood and Pratten is most abundant and characteristic but should be used with caution for it ranges higher. Rare and undiagnostic species are *Echinoconchus rodeoensis* Hernon (?), *Linoproductus ovatus* (Hall), *Orthotetes kaskaskiensis* (McChesney), *Gigantoproductus brazerianus* (Girty), *Composita trinuclea* (Hall), and *Dielasma shumardanum* (Miller). Most of these are characteristic of the younger *Punctospirifer transversa* zone.

The *Dictyoclostus parvus* zone usually spans the lower 200 feet of the Etherington formation from Mount Rae southward. Northwest at Banff, beds contained by the zone thin to about 100 feet and belong to lithologic equivalents of upper Mount Head. At Lake Minnewanka and north, the zone occupies the lower part of the Tunnel Mountain formation indicating a late Meramecian or early Chesterian age for these beds. This dating is at variance with that of Raasch (10, p. 117) who placed probable lateral equivalents of this unit at Eagle Creek (about thirty miles north of Lake Minnewanka) in the Permian. The writer prefers to interpret the Rocky Mountain–Rundle contact in the Banff, Lake Minnewanka, and Eagle Creek areas as diachronic rather than unconformable.

Punctospirifer transversa Zone

Punctospirifer transversa (McChesney) is diagnostic of this zone. In its absence the association of fairly abundant *Echinoconchus rodeoensis* Hernon (?), *Linoproductus ovatus* (Hall), *Orthotetes kaskaskiensis* (McChesney), *Spirifer arkansanus* Girty, and *Dielasma shumardanum* (Miller) is sufficient to recognize the zone. The zone extends over the middle 200 feet of the Etherington formation on Mount Rae and to the south. At Tunnel Mountain beds contained by the zone occupy the lower 120 feet of the Etherington, extending from 2,000 to 2,120 feet above the base of the Rundle group.

Diaphragmus cestriensis Zone

Fossils diagnostic of this zone are *Diaphragmus cestriensis* (Worthen) (= *D. elegens* Norwood and Pratten), *Dictyoclostus coloradoensis* (Girty) (?), *Spirifer cavecreekensis* Hernon, *Composita subquadrata* (Hall) and *Eumetria vera* (Hall). Associated with this fauna are rare specimens of *Echinoconchus rodeoensis* Hernon (?), *Linoproductus ovatus* (Hall), *Orthotetes kaskaskiensis* (McChesney), and *Spirifer leidyi* Norwood and Pratten.

Beds of the *D. cestriensis* zone comprise the upper 150 feet of Etherington on Mount Rae and the upper ninety-five feet of this formation on Tunnel

Mountain, that is, the uppermost type Rundle extending from about 2,120 to 2,215 feet above the base of the Rundle group. Lower beds of the overlying type Tunnel Moutain may belong within this zone but their fauna is too poorly preserved for accurate identification. The stratigraphic position of this zone with respect to most of the overlying type Tunnel Mountain formation suggests that the Tunnel Mountain here is late Chesterian or, more probably, Pennsylvanian in age. The writer considers that this formation becomes older east and north of Banff (see *Dictyoclostus parvus* zone).

Specimens from the Etherington formation, which the writer is assigning to *Spirifer cavecreekensis* Hernon, are probably forms which in the past have been called variously *Spirifer increbescens* Hall, *S. pellaensis* Weller, and *S. leidyi* Norwood and Pratten. These specimens are smaller, more transversely elongated, and have fewer lateral ribs than typical *S. increbescens*. They differ from *S. pellaensis* by having a more protuberent ventral umbo and in having ribs of the sinus approximately equal in strength. The fine, more numerous lateral ribs and three nearly equally defined sinal ribs distinguish *S. cavecreekensis* from *S. leidyi*. There is a rather high degree of variation within specimens referred to *S. cavecreekensis*, however, so that end members approaching *S. increbescens*, *S. pellaensis*, *S. matheri* (see below), and even *S. leidyi* have been noted.

Spirifer matheri Zone

The *Spirifer matheri* zone has been recognized at one locality in the Flathead area of the southern Rockies, where it occurs in uppermost Etherington above the *Diaphragmus cestriensis* zone. *Spirifer matheri* Dunbar and Condra with the associated species *Spirifer cavecreekensis* Hernon and *Composita subquadrata* (Hall) are considered diagnostic. The zone is dated as Pennsylvanian with reservations. Uncertainty exists as to both the validity and the age of this zone, as the writer is doubtful of the identity of the zone fossil *S. matheri*. As stated earlier (p. 49) there is a possibility that the writer's *S. matheri* may be but a variety of *S. cavecreekensis*. Thus the zone may be Mississippian.

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SECTION FOUR

The Nikanassin-Luscar Hiatus in the Canadian Rockies

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ABSTRACT

The basal Nikanassin of the type section in the central Alberta Foothills is known to yield fossils referable to the Oxfordian stage of the Jurassic. Floras with Luscar affinities are known to occur above Neocomian (Lower Cretaceous) marine deposits in the Peace River area. In type area the unconformable boundary between the Nikanassin and Luscar formations is defined by the Cadomin conglomerate. The hiatus indicated by this unconformity is represented in the Peace River basin by a continuous sequence of *Aucella*-bearing beds of the upper Nikanassin (Upper Jurassic) and lower Bullhead (Lower Cretaceous) group of formations.

TECTONIC implications of the Nikanassin–Luscar hiatus are gradually unfolding as the studies of marine strata for the discovery of oil in Western Canada supplement the previous studies of continental beds for the exploitation of coal. Studies of the Lower Cretaceous coal measures of Alberta twenty years ago (13) led the senior author to analyse the significance of the Blairmore (Cadomin) conglomerate which lies between the Jurassic Nikanassin and the Lower Cretaceous Luscar formations. Since that time the sediments spanning the gap represented by this hiatus have been recognized in that portion of the Foothills of the Canadian Rockies lying in the Peace River drainage area of British Columbia.

The sedimentation within the Peace River area is dominated by a strong autogeosynclinal downwarp, transverse to the Laramide structures of the Rockies. Recent publications (7; 4; 16) have emphasized the similar trend in the Peace River arch south of the autogeosynclinal downwarp. Of the two, the negative feature is the more pronounced. The stratigraphic section on the "arch," from Devonian time on, is similar to the section in Jasper Park. It appears to the writers that the Peace River "arch" is merely the up-tilted margin of the crustal platform of west-central Alberta, and simple diastrophism and periods of erosion account for most of its subsequent history. There was, apparently, local basement faulting on the arch in the late Paleozoic, but such structures appear to have had little effect on Mesozoic sedimentation. The more pronounced negative feature, the autogeosyncline, undoubtedly involved the basement as well and did affect the pattern of Mesozoic sedimentation, for in Mesozoic time in the portion of the Peace River Foothills in British Columbia there is a record of almost complete continuity of deposition from Triassic to Upper Cretaceous time. In addition, isopach maxima south of the Peace River for the various stages of sediments show that this downwarp is a mobile autogeosyncline and not a

static basin. The design of the isopachs indicates the filling of an embayment reaching in from the Pacific Ocean. The Pacific connection is demonstrated by fossil faunas present in this downwarp. As the writers have shown previously (15), all flooding of this area from Beltian time to the end of Triassic was from the Pacific Ocean. Frebold's map (5) of the Jurassic Fernie sea

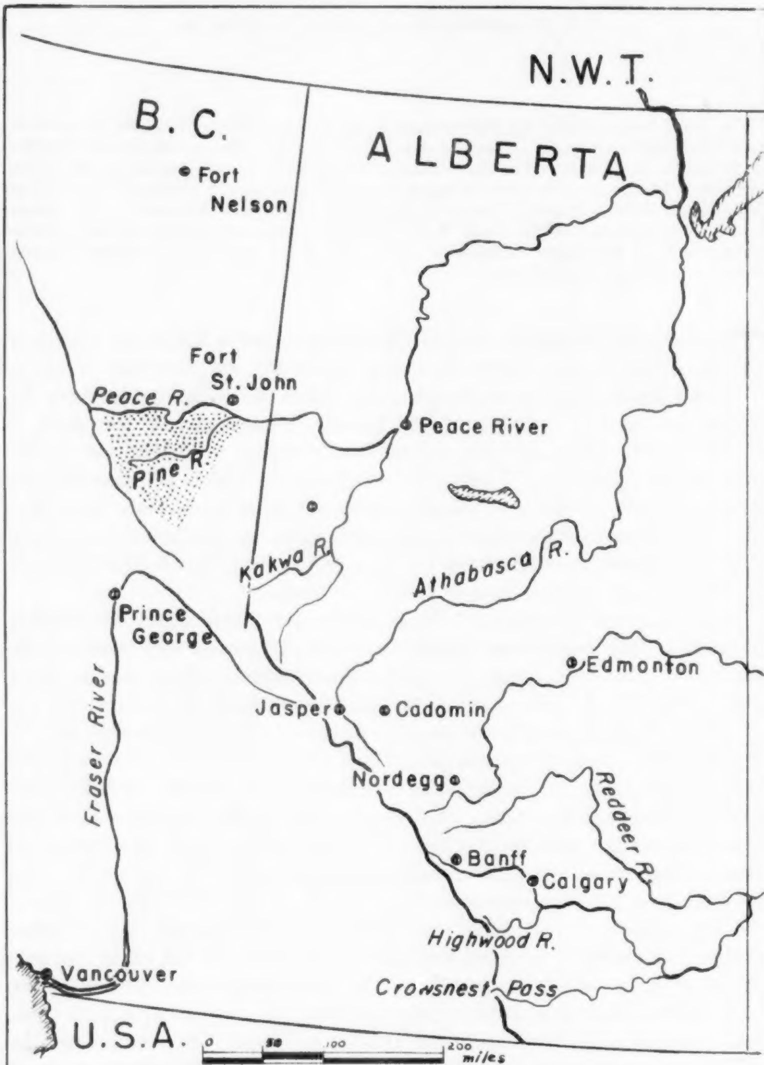

FIGURE 1.—Index map of Rocky Mountain region, with stippling to represent Peace River autogeosyncline

shows a widespread inundation of Alberta and Saskatchewan by Pacific waters. This was the last Pacific connection to reach Saskatchewan.

The advent of Upper Jurassic sands, both marine and continental, represents the uplift that expelled the Fernie sea from the interior of the continent. The positive movement that continued was most significant in the region of the Yukon to the north and the Montana "highland" to the south as revealed by the introduction of coal, erosional breaks, and conglomeratic phases. North of the Athabasca River marine conditions persisted till a much later date; and the most complete section is found in the Peace River embayment including marine beds as late as Valanginian (Lower Cretaceous) age. These marine Valanginian beds are overlain by continental coal-bearing

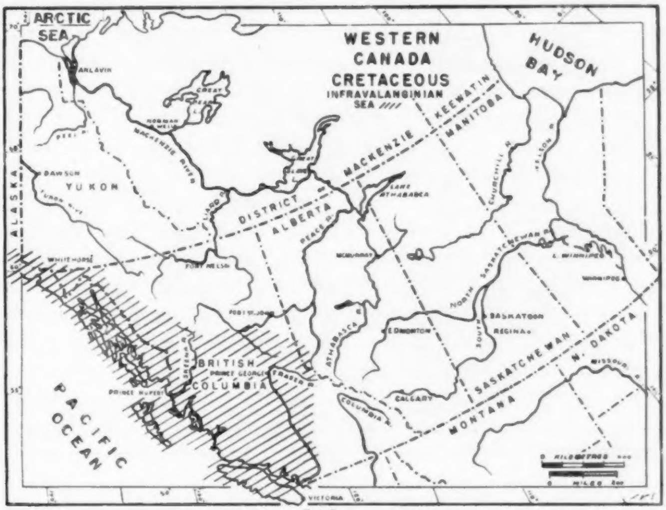

Fig 2

FIGURE 2.—Maximum known Pacific flooding in Infravalanginian time

beds (Gething) containing a Luscar flora. Thus Pacific connections were finally broken. Subsequent floodings from the Arctic and, later, from the Gulf of Mexico reoccupied the eastern portion of the Peace River autogeosyncline, depositing an additional ten thousand feet of marine Cretaceous sediments above the Gething formation. The realization of the persistence of the Peace River autogeosyncline through late Jurassic and early Cretaceous time led the writers to revisit the Pine Pass area to evaluate the extent of the break represented by the Nikanassin–Luscar hiatus.

In the Pine Pass, the full section of Fernie is represented on Lemoray Mountain and capped by sandstone beds carrying *Aucella* similar to those found in the base of the Nikanassin at Jasper. At the base of Mount Bickford, nine miles to the northeast, the writers measured 3,500 feet of sandstone carrying Upper Jurassic *Aucella*. The sandstones have an appearance

and habit similar to the lower part of the type section of Nikanassin strata and grade upwards into more shaly beds which are largely concealed and in excess of 500 feet in thickness. The coarser sandstones of the overlying Monteith formation carry the lowermost Cretaceous *Subcraspedites* cf. *groenlandicus* fauna in the immediate vicinity of Mount Bickford.[1] On Mount Bickford, Cretaceous *Aucella* are common in the Monteith formation. However, on Fisher Creek a loose block of Tithonian age carrying *Notostephanus* cf. *kurdistanense* and *Aucella piochii* indicates the presence of latest Jurassic beds in the same general locality.

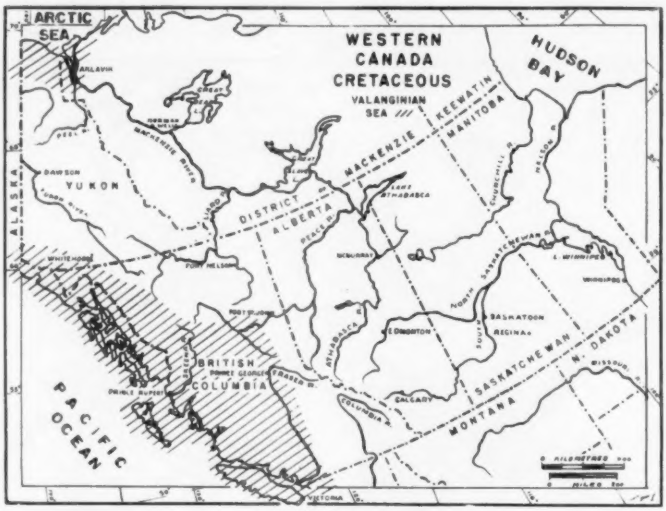

Fig 3

FIGURE 3.—Maximum known Pacific flooding in Valanginian time

The Jurassic–Cretaceous boundary occurs at or within the base of the Monteith formation. Just west of the type area of the latter and twenty miles to the northwest of Mount Bickford, the Monteith formation, Beattie Peaks, and the Monach formation represent a Cretaceous *Aucella*-bearing sequence of over 6,500 feet. The Monach is succeeded, in its type area, by 4,500 feet of non-marine beds of the Bullhead group, *viz.*, the Dunlevy and Gething formations. In the upper part of the Dunlevy and in the Gething formation, as reported by Dr. Bell (2), the flora is of the same age as that of the Luscar which he considers to belong to the Aptian stage. The Jurassic *Aucella*, previously noted from the Nikanassin at Jasper, are not later than Kimmeridgian age. It would appear, then, that the gap between the Nikanassin and the Cadomin conglomerate at the base of the Luscar represents most

[1]Personal communication from J. Jeletzky.

of the Portlandian, Tithonian, and Neocomian stages of the Jurassic and Cretaceous periods.

The Lower Blairmore formation of the southern Foothills is the equivalent of the Luscar and Moutain Park formations. The Fernie shale of the Crowsnest area yields an Oxfordian fauna and is succeeded by passage beds, presumably of Kimmeridgian age, as the base of the overlying Kootenay carries a Portlandian ammonite. Only the uppermost part of type Nikanassin can be considered as correlative with any part of the Kootenay. This would imply that the basal marine portion of the Kootenay represents the last phase of the late Jurassic Nikanassin flooding in the southern area. Marine conditions resulting in Nikanassin lithology persisted progressively later than Portlandian time in the area north of the Athabasca River until, at the Pine River, marine Tithonian, Infravalanginian, and Valanginian beds are known. However, at Kakwa River, midway between the Athabasca and the Pine rivers, marine conditions persisted only until Infravalanginian time and both marine Nikanassin and continental Kootenay type of lithologies are present in the succession. Because of its importance in solving the Nikanassin–Kootenay correlation, the writers wish to elaborate on the occurrence of these beds in the Kakwa River area.

A complete section of Fernie shale is exposed at Stinking Springs just north of Kakwa River. About 700 feet of marine shales are present. The shales have a limy phase at the base (Nordegg member) and lie disconformably on the lower part of the Upper Triassic. The upper part of the shales is silty and transitional with the overlying Nikanassin sandstone. The Nikanassin in this area normally consists of four members—an upper member consisting of shale with fine silt and sandstone, 370 feet in thickness with marine fossils; an upper sandstone member, 500 feet in thickness carrying *Pentacrinus* at the base; a middle shale member, several hundred feet in thickness carrying *Pentacrinus* and thickening very rapidly to the west; and a lower sandstone member about 500 feet thick, carrying *Aucella*.

The Kootenay formation outcrops to the west of Stinking Springs. Here the thickness of the Kootenay is 1,200 feet, and to the southwest, 5,400 feet. The thicker section of the Kootenay strata is readily divisible into two parts. The upper part, carrying coal seams and thick, medium-grained sandstones, spans 3,420 feet. The lower part, 1,975 feet thick, carries plant remains and, rarely, thin streaks of coaly material. It is composed of fine sandstones that grade transitionally into underlying marine Nikanassin beds. A sandstone bed carrying oysters marks the Nikanassin–Kootenay contact. The upper and lower Kootenay division is made on a conglomeratic sandstone that might indicate a stratigraphic hiatus. The thinning of the Kootenay to the northeast takes place by elimination of the coaly sequence at the top and erosion down into the lower Kootenay sequence. The lower Kootenay beds represent a shoreline or deltaic continuation of deposition and no stratigraphic hiatus is postulated at the base of the Kootenay.

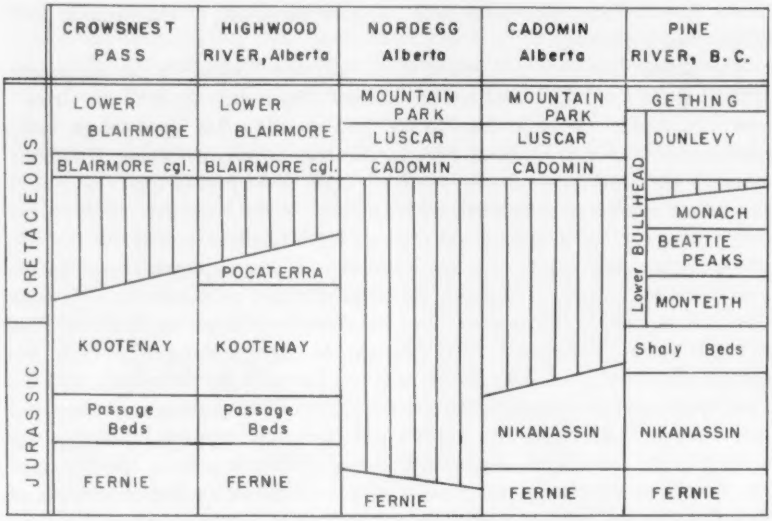

FIGURE 4.—Correlation chart of Jurassic–Early Cretaceous formations of the Canadian Rocky Mountains

At the top of the Kootenay there is an erosional break and the Cadomin conglomerate formation lies on the disconformity. At the first outcrop of the Cadomin formation west of Stinking Springs the beds are 160 feet thick and show two main conglomerate members. Westward the number of conglomerate beds increases. Above the Cadomin formation a complete section of Luscar formation, 1,600 feet thick, is exposed.

The fossil content of the Jurassic–Cretaceous beds in the Kakwa area is adequate to assess the stratigraphy. All parts of the Nikanassin in the Kakwa area carry *Aucella*, *Pentacrinus*, and a small scaphopod. This *Pentacrinus* fauna has been recognized continuously in the Nikanassin from Jasper to the Peace River. At the base of the formation in the Kakwa area *Aucella bronni* Rouiller is common. *A. bronni* is known from both the Lower Nikanassin and the passage beds with the underlying Fernie shale from the Athabasca River (Fiddle Creek) to the Peace River (inner Foothills). This distribution suggests a fluctuating, diachronic Nikanassin–Fernie contact. In the Kakwa area the youngest fauna of the marine Nikanassin carries *Mclearnia mclearni* Crickmay which, with Cretaceous *Aucella*, Crickmay (3) originally collected from the Infravalanginian of Harrison Lake, British Columbia. South of the Kakwa area no marine fauna as late as this is known from the Nikanassin beds. The youngest marine fauna known in the Kootenay formation is the Portlandian *Titanites* fauna from Fernie, British Columbia. However, to the north of the Kakwa area, marine faunas as late as Valanginian occur in the Peace River autogeosyncline.

The Kootenay plant-bearing facies is unknown in the autogeosyncline although the "salt and pepper" lithology of the Kootenay is common in the marine Bullhead strata (Monteith, etc.) above the Nikanassin lithology. Above the oyster bed, marking the top of the Nikanassin in the Kakwa area, a Kootenay flora is found, comprising the following diagnostic species: *Czekanowskia* cf. *rigida* Heer (known only from the lower member of the Kootenay in this area), *Cladophlebis heterophylla* Fontaine, *Gingko nana* Dawson, *Gingko* cf. *lepida* Heer, *Podozamites lanceolatus* (Lindley and Hutton), *Sagenopteris* spp., and numerous Conifers and Cycadeoids. This flora is clearly distinct from that of the succeeding Cadomin and Luscar floras. The break between the Kootenay and Luscar floras would tend to indicate a considerable period of erosion represented by the Cadomin–Kootenay unconformity in the Kakwa River area. There was a return to marine conditions in the earlier portion of the Luscar sedimentation (in the area along the Foothills from Nordegg, Alberta, north to the Pine River drainage in British Columbia) which is apparently of an age younger than *Aucella*, that is, post-Valanginian.

The reappearance of marine beds in the Luscar formation offers an explanation of the mechanism whereby the Cadomin (Blairmore) conglomerate formation was deposited penecontemporaneously over a lineal distance greater than 500 miles in the Canadian Foothills. The same tectonic subsidence that initiated the Luscar marine inundation apparently reduced the entire stream gradient from the headwaters in Montana to the drowned estuary in the Peace River area. This reduction in the competence of the stream spread the gravels over wide flood plains, and introduced the cover of sands, silts, and carbonaceous clays of the Luscar formation. The Cadomin conglomerate is apparently the product of one river's provenance as the assemblage of pebbles is little changed throughout. The writers assume that it represents the residual products of the late Palaeozoic and early Mesozoic strata to the east and south undergoing erosion during the Nikanassin–Luscar hiatus, as the same type of pebbles occur in the Pocaterra conglomerate and the late Kootenay at the beginning of the hiatus.

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